

THIRTY-FIFTH ANNUAL REPORT
OF THE
NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

1949

INCLUDING TECHNICAL REPORTS
NOS. 922 to 950



UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1951

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Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-fifth Annual Report of the Committee covering the fiscal year 1949.

HARRY S. TRUMAN.

THE WHITE HOUSE.
JANUARY 16, 1950.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., December 16, 1949.

DEAR MR. PRESIDENT: In compliance with the act of Congress approved March 3, 1915, as amended (U. S. C. 1946, title 50, sec. 153), I have the honor to submit herewith the Thirty-fifth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1949.

Achievement of flight faster than the speed of sound by American research airplanes has given a strong stimulus to the design of very high speed aircraft both in this country and abroad. The Committee has evidence of increasing international competition in aeronautical research and development. The stakes are high. Superior speed in military aircraft is essential to the success of air attack as well as air defense. In the age of atomic bombs it appears that no nation can win a war without control of the air.

During the past year the Committee has directed much of its effort to solutions of the complex problems of high-speed flight. By the achievement of successful supersonic flight there was gained for America a substantial advantage in the race for air leadership. This gain was made through the coordinated effort of scientists and engineers throughout the country—notably in the aircraft industry, the military establishment, and NACA—and supported by the work of educational institutions and other research agencies. The same teamwork is required to consolidate these gains and to push forward. The Congress has wisely provided for increasing the effectiveness of the team by authorizing the Unitary Wind Tunnel Plan for establishment of needed facilities for transonic and supersonic research, development, and evaluation. The Unitary Plan represents an extension of the teamwork idea initiated by the cooperative military-industry-NACA research-airplane program that led to achievement of supersonic flight. In that program forces were joined to produce research results. In the Unitary Plan the same forces will be joined to expedite the development and sound evaluation of practical aircraft capable of the superior performance required to meet an emergency.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

THE PRESIDENT,
The White House, Washington, D. C.

National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW., Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President, and serve as such without compensation.

JEROME C. HUNSAKER, Sc. D., Massachusetts Institute of Technology, *Chairman*

ALEXANDER WETMORE, Sc. D., Secretary, Smithsonian Institution, *Vice Chairman*

HON. JOHN R. ALISON, Assistant Secretary of Commerce.

DETLEV W. BRONK, Ph. D., President, Johns Hopkins University.

KARL T. COMPTON, Ph. D., Chairman, Research and Development Board, Department of Defense.

EDWARD U. CONDON, Ph. D., Director, National Bureau of Standards.

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R. M. HAZEN, B. S., Director of Engineering, Allison Division, General Motors Corp.

WILLIAM LITTLEWOOD, M. E., Vice President, Engineering, American Airlines, Inc.

THEODORE C. LONNQUEST, Rear Admiral, United States Navy, Deputy and Assistant Chief of the Bureau of Aeronautics.

DONALD L. PUTT, Major General, United States Air Force, Director of Research and Development, Office of the Chief of Staff, Matériel.

JOHN D. PRICE, Vice Admiral, United States Navy, Vice Chief of Naval Operations.

ARTHUR E. RAYMOND, Sc. D., Vice President, Engineering, Douglas Aircraft Co., Inc.

FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.

HON. DELOS W. RENTZEL, Administrator of Civil Aeronautics, Department of Commerce.

HOYT S. VANDENBERG, General, Chief of Staff, United States Air Force.

THEODORE P. WRIGHT, Sc. D., Vice President for Research, Cornell University.

HUGH L. DRYDEN, Ph. D., *Director*

JOHN W. CROWLEY, JR., B. S., *Associate Director for Research*

JOHN F. VICTORY, LL. D., *Executive Secretary*

E. H. CHAMBERLIN, *Executive Officer*

HENRY J. E. REID, D. Eng., Director, Langley Aeronautical Laboratory, Langley Field, Va.

SMITH J. DEFANCE, B. S., Director, Ames Aeronautical Laboratory, Moffett Field, Calif.

EDWARD R. SHARP, Sc. D., Director, Lewis Flight Propulsion Laboratory, Cleveland Airport, Cleveland, Ohio

TECHNICAL COMMITTEES

AERODYNAMICS

POWER PLANTS FOR AIRCRAFT

AIRCRAFT CONSTRUCTION

OPERATING PROBLEMS

INDUSTRY CONSULTING

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY AERONAUTICAL LABORATORY,
Langley Field, Va.

LEWIS FLIGHT PROPULSION LABORATORY,
Cleveland Airport, Cleveland, Ohio

AMES AERONAUTICAL LABORATORY,
Moffett Field, Calif.

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

OFFICE OF AERONAUTICAL INTELLIGENCE,
Washington, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

THIRTY-FIFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., November 17, 1949.

To the Congress of the United States:

In accordance with the act of Congress, approved March 3, 1915 (U. S. C. title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits its thirty-fifth annual report for the fiscal year 1949.

In the Committee's report last year it was stated that the American achievement of flight faster than the speed of sound by a special research airplane would influence our future concept of national security. It was pointed out that this accomplishment was acting as a stimulus to the design of very high-speed airplanes by removing concern relative to the existence of an unknown sonic barrier. During the past year the effects of this stimulus have become evident both here and abroad through supersonic flights by other experimental airplanes.

The demonstrated possibility of supersonic flight is a significant turning point in aircraft performance. For the future, we must accept the view that flight at supersonic speeds by practical military airplanes can be attained by any nation willing to make the effort. Another nation has apparently achieved success in developing an atomic explosion. It is logical to assume that an intensive effort is being made to develop a means for transporting atomic weapons with as high a degree of effectiveness as possible and at the same time to provide defense against invading aircraft armed with atomic weapons. Superior speed is generally acknowledged to be the most important single element in successful air attack and in defense against such an attack. Range also is important. The attainment of long range at supersonic speeds poses a most difficult problem.

For America to continue its present supremacy in the air will require that it develop military aircraft that can fly faster than sound. This places emphasis on research and development. As in the case of the atomic bomb, America cannot expect to enjoy an exclusive advantage. At best it can only plan by vigorous and timely research to stay ahead of any potential enemy in the development of aircraft of superior performance.

The Committee feels a sense of urgency in the conduct of its broad comprehensive programs of scientific research in aeronautics, which include the stimulation

and coordination of basic research in scientific and educational institutions. There is no excuse for a complacent attitude. We need to maintain technological superiority, in order that we may have the most modern aircraft as the backbone of American air power in being, on whatever basis it may be determined by the Congress to be necessary to afford a reasonable degree of security consistent with the national economy.

To explore more rapidly the little-known regions of transonic and supersonic flight speeds, the cooperative industry-military-NACA research airplane project, which commenced with the USAF X-1 and Navy D-558 airplanes, has grown to include more than a half-dozen airplane types. The scientific information obtained to date from this flight program has given aeronautics perhaps the greatest impetus in its history.

Notable during the past year has been the eagerness of aircraft designers to apply the new knowledge being obtained from the Committee's high-speed research program. Now that experimental supersonic flight has been attained, great efforts are being made by the Air Force and the Navy in fostering the design of operational transonic and supersonic aircraft. The Committee notes with satisfaction a healthy pressure upon it from the military air services and from the aircraft industry for advanced scientific data. This is the first occasion in peacetime history that organized research effort has been unable to stockpile scientific knowledge for future use. The demand is for advanced scientific knowledge for immediate application.

In the past fiscal year, the Committee placed in operation the third of its large scale supersonic wind tunnels. Each of these tunnels is being used to study fundamental aspects of supersonic aerodynamics and propulsion problems. For some time it has been evident that additional supersonic facilities are needed for development and evaluation purposes as well as for research. From this need has evolved what is known as the "Unitary Wind Tunnel Plan." Enabling legislation for this plan became public law on October 27, 1949.

The history of the Unitary Plan goes back to late 1945 when the military services and the Committee studied the possibilities of supersonic flight in its effect on the research, development, and evaluation effort required to insure leadership of the United States in the evolution of aircraft and missiles. The conclusions arrived at, including those of the Guided Missiles Committee of the Joint Chiefs of Staff, concerning their

special wind tunnel requirements, were available at the April 1946 meeting of the Committee where it was agreed that the recommendations of all agencies should be coordinated to eliminate duplication and nonessential items, and to evolve a single plan for the United States.

The desired coordination was effected by special panels of the Committee studying the questions in the period April 1946 to January 1947. The resulting Unitary Plan was approved by the Committee on January 24, 1947, and was forwarded to the Research and Development Board of the National Military Establishment (then the JRDB) and was approved by the heads of the armed services. The plan aimed at the foreseeable needs of the country in the next 10 years; it recommended allocation and operating responsibilities among the Navy, Air Force, and NACA for an integrated wind tunnel construction program. These wind tunnels will be available for the use of all interested agencies and the aircraft industry. Provision was made for improved research facilities at universities, not only to perform productive research but also to assure an output of qualified aerodynamicists to staff the tunnels contemplated under the Unitary Plan.

Many problems remain to be solved before tactically useful aircraft capable of sustained supersonic flight can be produced. The outstanding problems involve a better understanding of the transonic speed region through which supersonic aircraft must pass, and the development of propulsion systems giving higher thrust for longer periods of time, at increased efficiencies.

In the transonic speed region, an airplane encounters a mixture of subsonic and supersonic flow. The establishment of the physical laws governing such mixed flow will be extremely important. Since the study of transonic flow in conventional wind tunnels is not possible, the development of new experimental methods and facilities is required.

In the past few years the advent of new forms of propulsion challenged the resourcefulness of the aerodynamicist to utilize effectively the high thrusts made available. The challenge is now somewhat reversed, and it is necessary that means be found to provide improved propulsive systems for aircraft being designed for transonic and supersonic flight. Sufficient thrust is now available for short periods from rocket engines and jet engines with thrust augmentation arrangements. Progress is being made toward the development of adequate propulsion systems having the high efficiency necessary for flights of reasonable duration. What must be done is clear, but the problems are exceptionally difficult and intensive research is required for their solution.

In addition to the primary problems of high-speed

aerodynamics and propulsion, a considerable effort is required in the numerous and extensive fields of complementary research that are equally important to the achievement of useful supersonic flight. Thus, increased emphasis is being given to research on the problems of aircraft construction including such subjects as aeroelasticity, aerodynamic and impact loads, structural efficiency, and materials. Attention is also being given to research on such operational problems as icing, fire prevention, atmospheric turbulence, and emergency escape from high-speed aircraft.

The work of the Committee is in general directed toward the over-all objective of improving the performance, efficiency, and safety of both civil and military aircraft and of discovering and applying new scientific knowledge essential to continuing American leadership. The immediate objective is to solve, as quickly as facilities and personnel permit, the most pressing problems attendant on high-speed flight.

A matter of current interest is the application of turbopropellers and turbojets to transport aircraft. The British Government, through the Ministry of Supply, several years ago sponsored the development of new types of power plants solely for transport use, and financed the development of several transport aircraft incorporating these engines. The design and construction of such airplanes in the United States is dependent more on finding an acceptable method of financing of prototypes than on additional research. Successful commercial use of such aircraft will depend, however, on research to solve the many operational problems of high-speed transport airplanes.

There is one factor in the administration of research that should not be overlooked. This is the extreme pressure which arises, when budgets must be curtailed, to approve only those research projects which have an immediate bearing on current development. In the long run this is a fatal policy. Research naturally leads development. If the reverse were attempted, only minor improvements of existing types would result. Procurement-minded, short-range research could never produce such radical developments as supersonic flight, atomic power and radar. There is no surer way to fall behind than to perpetuate the old and forego the new by thinking only of today's production and procurement problems.

Parts I, II, and III of this annual report present a résumé of the scientific activities of the Committee, a description of the Committee's organization and membership, and the financial report for the fiscal year 1949.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

Part I—TECHNICAL ACTIVITIES

RESEARCH ORGANIZATION AND PROCEDURES

COMMITTEE LABORATORIES

Research of the National Advisory Committee for Aeronautics is conducted largely at its three laboratories—Langley Aeronautical Laboratory, Langley Field, Va.; Ames Aeronautical Laboratory, Moffett Field, Calif.; and Lewis Flight Propulsion Laboratory, Cleveland, Ohio. A subsidiary station is located at Wallops Island, Va., as a branch of the Langley Laboratory for conducting research on models in flight in the transonic and supersonic speed ranges. At Muroc Lake, Calif., is located the NACA High-Speed Flight Research Station for research on transonic and supersonic airplanes in flight. The total number of employees, both technical and administrative, at these five stations and headquarters in Washington was 6,938 at the end of the fiscal year 1949.

TECHNICAL COMMITTEES AND RESEARCH COORDINATION

In carrying out its function of coordinating aeronautical research the Committee is assisted by a group of technical committees and subcommittees. The members of these committees are chosen for their particular knowledge in a specific field of aeronautics. They are selected from other Government agencies concerned with aviation including the Department of Defense, from the aircraft and air transport industries, and from scientific and educational institutions. These committees provide for the interchange of ideas and prevention of research duplication except where parallel efforts are desired. There are four technical committees under the National Advisory Committee for Aeronautics:

1. Committee on Aerodynamics.
2. Committee on Power Plants for Aircraft.
3. Committee on Aircraft Construction.
4. Committee on Operating Problems.

Each committee is supported by three to eight technical subcommittees.

In addition to the four technical committees, there is an Industry Consulting Committee established to assist the main Committee in formulation of general policy. Membership of this Committee as well as the technical committees and subcommittees is listed in Part II of this report.

Research coordination is further effected through discussions between Committee technical personnel and the research staffs of the aviation industry, educational and scientific organizations, and other aeronautical agencies. Numerous conferences are held at Committee laboratories to examine research being conducted by the NACA and to see that the proper Government and private organizations are receiving full benefit from it. The Research Coordination Office is further assisted by a west coast representative who maintains close contact with the aeronautical research and engineering staffs of that geographical area.

RESEARCH SPONSORED IN SCIENTIFIC AND EDUCATIONAL INSTITUTIONS

To utilize most effectively the aeronautical research talents and facilities of the Nation, the NACA sponsors research in universities and other nonprofit scientific institutions. Through this sponsorship the NACA has access to a diversity of specialized talent in mathematics, physics, and engineering, which has contributed much valuable research in many fields of aeronautical importance. By thus tapping a reservoir of specialized competence and unique research facilities which would not otherwise have been brought to bear on pressing aeronautical problems, it is possible to complement the research carried on in NACA laboratories. This activity has the additional desirable advantage of training graduate students in practical research techniques.

Transonic aerodynamic research, and investigations of helicopter characteristics, boundary-layer flow, the nature of turbulence, and the physical properties of air under the extreme conditions of very high altitude and speed have been instituted. The development and evaluation of high-temperature alloys and ceramic coatings for turbine blades in gas-turbine power plants are continuing under NACA sponsorship, and the properties of aircraft structures and structural materials, and the mechanisms of failures in each, are under investigation in a number of institutions. Problems involving bearings and lubricants, pressurized cabins, combustion, and personal aircraft operation are also included in the projects supported by NACA contracts. These various research projects are described in greater detail

under the headings of the committees and subcommittees concerned.

During this year the NACA has sponsored new research on fundamental aeronautical problems at the National Bureau of Standards, Brown University, Battelle Memorial Institute, Polytechnic Institute of Brooklyn, California Institute of Technology, University of California, Cornell University, Forest Products Laboratory, Georgia Institute of Technology, Harvard University, Iowa State College, Johns Hopkins University, Massachusetts Institute of Technology, University of Michigan, University of Minnesota, Mount Washington Observatory, University of Notre Dame, Ohio State University, Oregon State College, Princeton University, Stanford University, Syracuse University, Agricultural and Mechanical College of Texas, and University of Washington.

RESEARCH INFORMATION

Research results obtained in the Committee's laboratories and through research contracts are distributed in the form of Committee publications. Formal Reports, printed by the Government Printing Office, contain unclassified information and are available to the general public from the Superintendent of Documents. Technical Notes, released by the Committee in limited numbers, also contain unclassified research results of a more or less interim nature and are distributed to interested organizations throughout the country. Frequently, research results which will ultimately be published in Report form are issued initially as Technical Notes in the interest of speedy dissemination of data to American technical people and organizations. Translations of foreign material are issued in the form of Technical Memorandums.

In addition to unclassified publications the Committee prepares a large number of reports containing classified research information. For reasons of national security, these reports are controlled in their circulation. From time to time the classified reports are examined to determine whether it is in the national interest to declassify them. If it is found desirable to declassify the reports, they are then published as unclassified papers.

Another important means of transmitting quickly and efficiently the latest information in a particular field of research directly to designers and engineers working in that field is the holding of technical con-

ferences from time to time at an appropriate NACA laboratory. Several conferences of this nature were held during the past year.

The Office of Aeronautical Intelligence was established in 1918 as an integral part of the Committee's activities. Its functions are the collection and classification of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, and its dissemination to the Department of Defense, aircraft manufacturers, educational institutions, and other interested people. American and foreign reports obtained are analyzed, classified, and brought to the attention of the proper persons through the medium of public and confidential bulletins.

AERONAUTICAL INVENTIONS

By act of Congress, approved July 2, 1926 (U. S. C. title 10, sec. 310-r), an Aeronautical Patents and Design Board was established consisting of the Assistant Secretaries for Air of the Departments of War, Navy, and Commerce. In accordance with that act as amended by an act, approved March 3, 1927, the National Advisory Committee for Aeronautics is charged with the function of analyzing and reporting upon the technical merits of aeronautical inventions and designs submitted to any agency of the Government. The Aeronautical Patents and Design Board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed \$75,000."

Recognizing its obligation to the public in this respect the Committee has continued to accord to all correspondence on such matters full consideration. All proposals received have been carefully analyzed and evaluated and the submitters have been advised concerning the probable merits of their suggestions. Many personal interviews have been granted inventors who visited the Committee's offices, and technical information has been supplied when requested.

* * * * *

The following detailed summary of research, completed during the fiscal year 1949, is organized to reflect the areas of research over which each technical committee and related subcommittee have cognizance.

AERODYNAMIC RESEARCH

Flights of man-carrying aircraft at speeds greater than the speed of sound have up to the present time been of very limited duration. Much research remains to be accomplished to make possible the design of more practical transonic and supersonic aircraft. While real progress has been made during the past year in exploration of new ideas in high-speed aerodynamics, considerable effort has also been expended in obtaining clearer understandings of previous research findings. In view of the present nature of the problem, the NACA has undertaken extensive studies of transonic and supersonic air flows with a view to providing additional aerodynamic information required for airplane and missile design. New and unconventional high-speed airplane configurations have further dictated that additional emphasis be placed on studies at subsonic speeds of take-off and landing characteristics. Studies of subsonic boundary layers have likewise been extended to provide a more thorough understanding of the phenomena as related to the new configurations and to assist in achieving improvements in performance of more conventional aircraft flying at subsonic speeds. Exploratory research on the nature of air flow at very high supersonic speeds has also been undertaken and the development of new research equipment for this purpose is also under way.

It is apparent from the details of the report which follows that the term "aerodynamic research" has been applied in a general sense to broad areas of the NACA's scientific effort. Accordingly, the scope of the current activities of the Committee on Aerodynamics includes

consideration of many problems of flight experienced at subsonic, transonic, and supersonic speeds which are directly, or in some cases indirectly, related to aerodynamics. The Committee on Aerodynamics is aided in its review of this broad field of research by the Subcommittees on Fluid Mechanics, High-Speed Aerodynamics, Stability and Control, Internal Flow, Seaplanes, Propellers for Aircraft, Helicopters, and the Special Subcommittee on the Upper Atmosphere. During the past year a new Subcommittee on Fluid Mechanics was created to review and coordinate the rapidly expanding research in this field. The Special Subcommittee on Research Problems of Transonic Aircraft Design, mentioned in the previous annual report, was discharged in view of the completion of its special assignment. The Subcommittee on High-Speed Aerodynamics was reorganized in order that it might devote more attention to the design problems of missiles and airplanes, and assume the duties previously assigned to the Special Subcommittee on Research Problems of Transonic Aircraft Design. Research on air loads, effects of wing flexibility, dynamic maximum lift, flap effectiveness, and pressure distribution studies are discussed in the section "Airframe Construction Research" under activities of the Subcommittee on Aircraft Loads.

In order to promote early use of the research results, a technical conference on supersonic aerodynamics was held early in the fiscal year at the Ames Laboratory, with representatives of the military services and the aircraft industry. Some of the Committee's recent work in aerodynamics is described in the following sections.

COMMITTEE ON AERODYNAMICS

Airfoils

Because of the need for airfoil data at high Reynolds numbers the aerodynamic characteristics of a number of NACA 6-series airfoils, in both smooth and rough conditions, were determined experimentally at Reynolds numbers of 15,000,000, 20,000,000, and 25,000,000, and reported in Technical Note 1773. The investigation included a systematic study of the effects of airfoil thickness ratio, thickness distribution, and camber upon the aerodynamic characteristics of the airfoils at the different Reynolds numbers. One of the airfoils was also studied with a split flap. A particularly interesting result was the relatively large increase in the maximum lift coefficient of the 6-percent-thick sections as the Reynolds number was increased from 15,000,000 to 25,000,000.

A compilation has been made of data obtained from tests in the Langley two-dimensional low-turbulence

tunnels of a large number of miscellaneous airfoils. The airfoils consist of 14 modified or unconventional NACA 6-series sections and 20 other sections of special design. The aerodynamic characteristics of these airfoils extend over a range of Reynolds number from 3,000,000 to 9,000,000.

The accuracy of the method described in Report 824 ("Summary of Airfoil Data") for rapidly calculating the increment in the velocity distribution about a symmetrical airfoil due to angle of attack has been investigated. An analytical study was made of the accuracy of the method by the use of the exact theory of Theodorsen and Garrick for the potential flow about arbitrary airfoils. The results of the study reported in Technical Note 1884 show that the method of Report 824 evaluates the effect of angle of attack on the net velocity at any point of a symmetrical airfoil with a maximum error that is proportional to the cosine of the angle of attack.

A theoretical method has been studied at the Lewis Laboratory for calculating the velocity distribution on arbitrary airfoils in closed subsonic wind tunnels by conformal mapping. This study is reported in Technical Note 1899.

High-Lift Devices

In an effort to improve the maximum lift and stalling characteristics of moderately thin airfoils, modifications of the contour very near the leading edge of an NACA 63₁-012 airfoil section have been investigated in the Ames 7- by 10-foot wind tunnels. The modifications included increased leading-edge radii and camber and several nose flaps with increased leading-edge radii. The basic airfoil had a leading-edge radius of 0.0109 chord and stalled abruptly at a lift coefficient of 1.36. No turbulent separation was evident before the stall and the stall occurred because of a sudden failure of the separated laminar boundary layer near the leading edge to reattach to the airfoil surface. Maximum lift was followed by a large loss of lift. Increasing the leading-edge radius increased maximum lift and the angle of attack for maximum lift; however, the stall remained abrupt with a large loss of lift beyond the maximum. The nose flaps and increased camber near the leading edge in conjunction with an increased leading-edge radius provided additional increases of maximum lift; however, again a large loss of lift followed. With a leading-edge radius of 0.035 chord added completely below the upper surface of the basic airfoil, a maximum lift coefficient of 1.71 was obtained. Some of the modifications tested initiated turbulent separation near the trailing edge along with the increase of maximum lift; however, the stall appeared to be controlled by a sudden failure of the separated laminar boundary layer near the leading edge to reattach to the airfoil surface.

Results have recently been obtained of tests in the Langley two-dimensional low-turbulence tunnels of leading-edge slats on two airfoils of 9- and 12-percent thickness to investigate means of improving the maximum lift and stalling characteristics of thin wings necessary for high-speed flight. The results indicated that, in combination with a split trailing-edge flap, the leading-edge slat increased the maximum section lift coefficient by 0.81 and 0.60 on the 9- and 12-percent-thick airfoils, respectively. The slats also increased the angle of stall and caused the stall to become more gradual.

Although sharp-edged airfoil sections offer considerable promise for application to certain supersonic aircraft, they have a low maximum lift and a rapid increase of drag with lift at low speeds. An investigation of nose and trailing-edge flaps on a modified double-wedge section was therefore undertaken in the Ames

7- by 10-foot wind tunnel to evaluate the effects of these flaps on the aerodynamic characteristics of the section.

The basic airfoil section with flaps undeflected had a maximum lift coefficient of 0.84. With the trailing-edge flap deflected 60° and the 0.16-chord nose flap deflected 30°, a maximum lift coefficient of 1.96 was obtained. Variation of the chord of the nose flap had little effect on the maximum lift; however, the effect on the angle of attack for zero lift was rather pronounced. Increasing the deflection or the chord of the nose flap or the deflection of the trailing-edge flap resulted in more negative pitching moments. Considerable reductions of drag at high lift coefficients were noted for suitable combinations of nose-flap and trailing-edge-flap deflections. The lift coefficient for minimum drag increased with increasing chord of the nose flap with the net result that the largest chord flaps provided the least drag at the highest lift coefficients.

Wings

An exploratory investigation to determine the aerodynamic effects of camber on a 60° apex triangular-wing model has been conducted in the Langley 300-mph 7- by 10-foot tunnel. Camber variation was accomplished through the deflection of full-span round-leading-edge flaps and 25° beveled-leading-edge flaps on a flat-sided, triangular-plan-form wing.

A 63° sweptback wing being studied in several of the facilities of the Ames Laboratory has been investigated in the 7- by 10-foot wind tunnel to evaluate the effectiveness of various controls and lift-increasing devices. The results indicate a radical reduction of longitudinal stability at moderate lift coefficients for the basic wing. The reduction of stability was roughly equivalent to a 50-percent mean-aerodynamic-chord shift in neutral point. The large reduction of longitudinal stability can be delayed to a higher lift coefficient by incorporating either a full-span nose flap or drooped nose with a half-span split flap at the trailing edge and utilizing an elevon for balance.

The stalling and maximum lift characteristics of wing plan forms suitable for current high-speed airplane designs have required a large amount of research effort. These characteristics are strongly affected by Reynolds number. Facilities capable of tests at essentially full-scale Reynolds numbers are required. Results from the Langley low-turbulence, Langley full-scale, Langley 19-foot, Ames 40- by 80-foot, and Ames 12-foot tunnels can be used to predict the behavior of air flow on wings at landing speeds.

A series of swept wings has been designed on the basis of the analysis presented in Technical Note 1772 to determine at large scale the extent to which camber and twist will improve the low-speed characteristics of

thin sweptback wings. Wings having 45° and 60° of sweepback and three values of twist and camber have been investigated in the Ames 40- by 80-foot wind tunnel. The results show that even moderate twist and camber, such as appear suitable for high-speed flight, will produce marked improvements in the low-speed characteristics of such wings. It is anticipated that further refinement will enable full realization of the theoretical possibilities of these wings which are considerably better than those of untwisted, uncambered swept wings.

An analytical study has been made of the landing-flare paths of hypothetical airplanes covering a wide range of maximum lift coefficient, wing loading, and lift-drag ratio. Generalized charts as well as a step-by-step method of analysis are presented in Technical Note 1930 for predicting the power-off landing-flare characteristics covering the conditions of various types of high-lift devices. From power-off considerations, airplanes having very low lift-drag ratios and high stalling speeds require excessive horizontal landing distances, high rates of descent, and high altitudes at the start of the flare maneuver. These landing considerations are expected to have considerable influence on the ultimate selection of wing configurations for high-speed airplanes.

The low-speed characteristics of an equilateral triangular wing having 10-percent-thick biconvex sections have been determined in the Langley full-scale tunnel. The effects of flaps on the maximum lift coefficient and on the lift-drag ratio were determined, and an analysis was made of the corresponding power-off landing characteristics. The effects of a fin on lateral and directional stability were also determined.

The effects on maximum lift of variations in the span and deflection of trailing-edge split flaps, operating in conjunction with a 0.58-span leading-edge flap on a wing of 42° sweepback and aspect ratio of 4, have been investigated in the Langley 19-foot pressure tunnel. The maximum-lift results were evaluated in terms of the landing characteristics in order to define the optimum combination of leading-edge and trailing-edge flaps.

An investigation was made in the Langley two-dimensional low-turbulence pressure tunnel of a semi-span model of a 42° sweptback wing of aspect ratio 4, which had previously been tested in a full-span arrangement in the Langley 19-foot pressure tunnel, to obtain an indication of the validity of the semispan method of obtaining aerodynamic data in this particular arrangement. This investigation indicates that data obtained from semispan-wing tests may be expected to be in good agreement with data obtained from full-span tests of the wing alone except for unusually sensitive configurations, where the lift distribution is such

that small disturbances produced by the tunnel-wall boundary layer may cause a radical change in the location of the original stall or in the manner in which the stall progresses.

Boundary-Layer Investigations

Boundary-layer studies. A continued study of the boundary-layer and stalling characteristics of airfoil sections in the Ames 7- by 10-foot wind tunnels has added much to the understanding of the mechanism of the stall of thin airfoils. It has been shown that there are, in general, three types of airfoil stall: (1) That resulting from turbulent separation beginning near the trailing edge and gradually progressing forward along the airfoil upper surface as the angle of attack is increased; (2) that resulting from the sudden failure of a separated boundary layer near the leading edge to reattach to the airfoil upper surface at the angle of attack for maximum lift; and (3) that resulting from the separation of flow from the leading edge but reattaching to the airfoil surface at positions progressively farther downstream as the angle of attack is increased. The first type of stall appears on relatively thick airfoil sections and the last type is evident on thin, sharp-edged sections. The intermediate type appears on sections of moderate thickness. These types of stall are found separately or in combination, depending on the airfoil under consideration.

The results of Technical Note 1894 indicate that for an NACA 63-009 section there was a short region of separated laminar flow near the leading edge prior to the attainment of maximum lift. The separated region decreased in extent as the angle of attack was increased. Maximum lift was attained when the separated laminar boundary layer failed to reattach to the airfoil surface. Other tests have shown that, with a modified double-wedge section, a form of separation appeared at the leading edge for a very low angle of attack and the separated region increased in extent as the angle of attack was increased. The flow over the NACA 63-009 section for angles of attack greater than that for maximum lift was similar to the flow over the double-wedge section for angles of attack less than that for maximum lift. Tests of an NACA 64A006 section (Technical Note 1923) have indicated that, at an angle of attack of about 5° , the flow changed abruptly from a type similar to that for the NACA 63-009 section before its stall to a type similar to that for the modified double-wedge section before its stall.

Boundary-layer control. An extensive study of the use of boundary-layer control as a means of improving the aerodynamic characteristics of airfoil sections is under way in the Langley low-turbulence section.

An investigation was made to determine the effectiveness of boundary-layer control together with relatively

small deflections of a plain flap as a means of increasing the lift-drag ratio. The boundary-layer control was applied through a single suction slot located just behind the hinge line of the plain flap. The airfoil employed in the two-dimensional investigation was the NACA 65, 3-418. The results indicate that the maximum ratio of lift to total drag of finite-span wings made up entirely of NACA 65, 3-418 airfoil sections would not be improved by this type of boundary-layer control if the wings were in the aerodynamically smooth condition. For the rough surface condition, the results indicate that the boundary-layer control would increase the maximum ratio of lift to total drag.

Wing sections suitable for high-speed applications usually stall abruptly with a large loss of lift at relatively low values of maximum lift because of the failure of a separated laminar flow near the leading edge to reattach to the airfoil surface. It has been demonstrated previously in the Ames 7- by 10-foot wind tunnel that a suction slot near the leading edge was effective in delaying the complete flow separation, and increased the maximum lift about one-third above that of the basic section. Turbulent separation occurred at the trailing edge prior to the attainment of maximum lift; however, it could not be shown that the stall was entirely the result of turbulent separation. To determine whether or not the nose slot was capable of holding the flow on the surface at higher values of lift, a second suction slot was installed at the midchord of the model to control the growth of the turbulent boundary layer over the rear portion of the model. It was found that the operation of the midchord slot in conjunction with the nose slot resulted in substantial gains in maximum lift over that obtained with nose suction alone. The cause of the stall with combined nose and midchord suction is uncertain; however, it was demonstrated that the nose suction slot combined with the midchord slot was effective at lifts greater than maximum lift with the nose slot alone.

An exploratory investigation was made at the Langley Laboratory of boundary-layer control through a porous leading edge as a means of delaying leading-edge separation and thus increasing the maximum lift coefficient. The NACA 64A212 airfoil was employed in the investigation. The results, which are reported in Technical Note 1741, indicate that the effectiveness of the boundary-layer control in improving the maximum lift coefficient is about the same as would be obtained from a well-designed leading-edge slot.

A study has been undertaken at the Ames 40- by 80-foot wind tunnel to determine the possible gains resulting from the application of boundary-layer control to a sweptback wing by means of porous suction at the leading edge in conjunction with circulation control. Preliminary results have established that the porous suction

must be applied over the entire span of the leading edge and over about 5 percent of the chord. With such control it was found possible to delay the appearance of leading-edge separation to at least the extent possible with leading-edge flaps. With the general requirements determined from the preliminary tests it is anticipated that further studies will yield a distribution of leading-edge suction producing even more favorable results.

The problem of reducing the profile-drag coefficient of airfoils by increasing the relative extent of laminar flow was considered in some detail at the Langley Laboratory. A two-dimensional wind-tunnel investigation reported in Technical Note 1905 was made of an NACA 64A010 airfoil having a porous surface of sintered bronze to determine the reduction in section drag coefficient that might be obtained at large Reynolds numbers by the use of continuous boundary-layer suction through the surfaces of the model. Combined wake and suction drags lower than the drag of the plain airfoil were obtained up to Reynolds numbers of 8,000,000. The model surfaces were neither aerodynamically smooth nor fair, which indicated that the suction had some stabilizing effect on the laminar boundary layer. Net drag reductions could not be obtained with this model at Reynolds numbers higher than 8,000,000.

The study of the application of boundary-layer control to a sweptforward wing has been completed at the Ames 40- by 80-foot wind tunnel. Satisfactory leading-edge flaps were found and boundary-layer control slots were placed at various chordwise and spanwise positions on the wing upper surface. The optimum position for applying boundary-layer control, however, was found to be a slot placed in the fuselage next to the wing upper surface and extending a short distance fore and aft of the hinge line of the nose flap.

In an effort to clarify the present status of research on boundary-layer control and its possible applications in aeronautics, a survey and evaluation were made of the results obtained from numerous individual investigations of various applications of boundary-layer control.

The results of the survey indicate that sufficient information is not available to permit the practical application of some types of boundary-layer control and that other types do not promise sufficient increases in airplane performance to warrant their use. The application of boundary-layer control which appears to offer the most immediate promise of improved airplane performance is the use of suction to eliminate turbulent separation over the rear of very thick airfoils. The prevention of turbulent separation on such airfoils permits their use as root sections of wings having very high aspect ratio. This application should result in substantial improvements in lift-drag ratio and range of long-range relatively slow aircraft.

Research on the use of multiple slots for the control of the laminar boundary layer has shown in general that at low Reynolds numbers it is possible to extend the laminar layer in a region of adverse pressure gradient practically to the trailing edge of an airfoil with a small expenditure of power, such that large net drag savings were realized. Studies are under way in an attempt to achieve extensive laminar flow at flight values of the Reynolds numbers.

Research Equipment and Techniques

New wind tunnels. Several new supersonic research facilities were put into operation during 1949. Among these facilities were three large supersonic tunnels, the 4- by 4-foot wind tunnel at the Langley Laboratory, the 6- by 6-foot wind tunnel at the Ames Laboratory, and the 8- by 6-foot wind tunnel at the Lewis Laboratory. The first two of these tunnels are of the variable-pressure type which permits investigations to be carried out over a range of Reynolds number. A range of supersonic Mach number is provided for in all three tunnels. In the Langley tunnel, Mach number variation is accomplished in fixed increments by means of flexible walls which are held to the correct shape by means of templates; the Lewis tunnel utilizes flexible walls which are continuously adjustable; and the Ames tunnel utilizes a new type of asymmetric supersonic nozzle which, like the Lewis arrangement, permits the Mach number of the tunnel to be varied continuously.

Blow-down tunnel instrumentation. Many wind tunnels of the blow-down type, in which air is compressed in a large chamber and then released through the tunnel, are limited to test runs of a very short duration. Measurements in these tunnels are either of transient phenomena which are continuously and rapidly changing or of quantities which attain a steady value for only a fraction of a second. One of these tunnels has a steady-state run of approximately 0.02 second during which measurements can be made. The instrumentation included a strain-gage sting balance for measurement of drag on the model, shadowgraph equipment for obtaining photographs of the rapid development of the shock pattern caused by the model, and controls to synchronize the instruments within the brief running time.

Wind-tunnel corrections. In the Langley full-scale analysis section several studies have been made of the problem of corrections for wind-tunnel-wall interference on test results. In Technical Note 1748 is given a general graphical procedure for calculating tunnel-induced-upwash angles for swept and yawed wings, both at the wing and at the tail. The required charts for a number of existing wind tunnels are included in the paper. In Technical Note 1826 an exhaustive analy-

sis has been made of the wind-tunnel interference in open wind tunnels with consideration for the effect of the closed entrance and exit bells. This study was made primarily in order to determine corrections for helicopter tests in the Langley full-scale tunnel, where the large rotor disk extends so far forward that the presence of the entrance bell cannot be neglected. The report discusses the basic phenomena involved, derives methods for determining the interference, and presents many calculated results.

Computations have been made in the Langley 7- by 10-foot-tunnels section in which the numerical values of the calculated boundary-induced-upwash angles necessary for the determination of the jet-boundary corrections for swept reflection-plane models mounted vertically in 7- by 10-foot, closed, rectangular wind tunnels have been evaluated. A few calculations made by using these values of upwash indicated that, for plan forms having taper ratios of about $\frac{1}{2}$, sweep has essentially no effect on the correction. Except for extreme cases of inverse taper the effect of sweep on the average induced angle appears to be less than 10 percent for sweep angles up to 60° . The results of this investigation are presented in Technical Note 1752.

Study of airspeed indicator installations. Calibrations of the static-pressure or "position" errors of the service airspeed installations of 10 present-day airplanes are presented in Technical Note 1892. Tests were conducted from speeds near the stall to maximum indicated speeds not exceeding 260 miles per hour. Analysis of the data presented showed that the static-pressure error for static vents on the rear section of the fuselage remained approximately constant with angle of attack and became more negative with flap deflection. The static-pressure errors for the wing, fuselage-nose, and vertical-tail installations became more negative with increasing angle of attack and more positive with flap deflection; the effect of engine power for these installations followed no consistent trend.

Response of pressure-measuring systems. Of major interest in many test installations is the response of pressure-distribution systems to rapidly varying pressures, both where these pressures must be accurately measured and where unwanted oscillations must be filtered out or eliminated. Technical Note 1819 presents a method for calculating the response of pressure-measuring systems to steady-state sinusoidally varying pressures. The pressure system is assumed to consist of an inlet restriction, tubing length, and connected instrument volume. The material presented is limited by the fact that no theoretical method of predicting the attenuation characteristics of the tubing is given. This limitation is not severe, however, as these characteristics may be experimentally determined for given

tube sizes and pressure frequencies. Experimental data for some sample systems tested are presented and show good agreement with calculated values. The results are presented in such fashion that the qualitative effect of varying the dimensions of system components is apparent. It is therefore possible, once the attenuation characteristics of the tube are determined, to design a system with a required frequency response.

SUBCOMMITTEE ON HIGH-SPEED AERODYNAMICS

Airfoils and Wings at Transonic Speeds

The study of airfoils at high speeds has continued to receive emphasis in the Committee's research programs. Several airfoil investigations were completed in 1949. A static-pressure investigation of the two-dimensional flow field in the neighborhood of two NACA 6-series airfoils at high subsonic speeds was conducted in the Langley rectangular high-speed tunnel and is reported in Technical Note 1873. Pressure measurements were made by means of a large number of orifices in the model end plate which was fitted flush with the tunnel wall. Reasonable agreement between theory and experiment was obtained for Mach numbers up to the critical values except at high angles of attack.

A two-dimensional pressure-distribution investigation of NACA 64₁-012 and 64₁A012 airfoils was carried out in the Langley rectangular high-speed tunnel to determine the effect of removing the cusp from the trailing edge. A similar investigation on thinner sections was carried out in the Ames 1- by 3½-foot high-speed wind tunnel in which the NACA 64-010 and 64A010 airfoils were employed. A study was made in the Langley rectangular high-speed tunnel of eight 6-percent-thick airfoils incorporating sharp and round leading edges. The aerodynamic characteristics of each airfoil were determined from the pressure-distribution data. A new series of airfoil sections, designated the NACA 8-series, was designed to have favorable lift characteristics at supercritical Mach numbers. Expectations were confirmed by results of wind-tunnel investigation to the extent that little or no variation in lift coefficient was found up to Mach numbers of about 0.9 at the constant design angle of attack. It was not found possible, however, to improve the lift-curve slope or the drag at supercritical speeds by use of these airfoils.

The linearized equations of compressible flow were studied for the case of near-sonic speeds and results were obtained for the time-dependent motion of two-dimensional airfoils and for particular steady-state three-dimensional lifting-surface problems at Mach number 1. These results have been reported in Technical Note 1824. Studies in the Langley 16-foot high-speed tunnel of the effects of compressibility on the

maximum lift characteristics of unswept wings have been extended to include the effects of deflected split flaps as reported in Technical Note 1759. The flaps were shown to be effective in producing increases in maximum lift at all speeds up to the maximum test value ($M=0.7$). Although the flaps increased the values of maximum lift over the test speed range, the trend of maximum lift with the increasing Mach number was similar to that previously shown for plain wings. Further studies on other wings employing different airfoil sections have been made to investigate the effect of airfoil section on wing maximum lift characteristics (Technical Note 1877).

A systematic series of several unswept wings of varying aspect ratio has been investigated at large scales and high subsonic Mach numbers in the Ames 16-foot high-speed wind tunnel. A thin unswept wing of low aspect ratio has been investigated at the Ames Laboratory by means of the NACA wing-flow method and the results have been compared with wind-tunnel results and with subsonic and supersonic wing theory.

The merits of the swept-wing plan form at transonic speeds have been established qualitatively from both theoretical and experimental investigations. The full exploitation of such plan forms, however, requires further investigation. Several investigations were made during the past year which will add to the body of information required for proper design of such wings. An investigation was conducted in the Ames 12-foot low-turbulence pressure wind tunnel on a swept wing having 37° sweepback of the leading edge. The aerodynamic characteristics and load distribution for this wing were measured and compared with theoretical estimates for Mach numbers up to 0.94 at constant Reynolds numbers in the range from about 1,000,000 to 3,000,000. A theoretical method for defining critical flow conditions at high Mach numbers was found to be in good agreement with experimental results and thus to offer a satisfactory means by which the Mach number for drag divergence could be estimated for this wing. Further investigation is required to establish the degree of applicability of the results to other swept wings and to problems related to the effects of fuselage and nacelle interference on such wings.

A coordinated research program to determine the characteristics of a configuration incorporating a wing of 63° sweepback has been continued. A model of this configuration has been investigated over a wide range of subsonic and supersonic Mach number in the Ames 1- by 3½-foot high-speed wind tunnel and another model incorporating certain special features designed to improve its characteristics has been investigated at relatively large scale and high subsonic Mach numbers in the Ames 12-foot high-speed tunnel.

A study was made in the Langley 8-foot high-speed tunnel to determine the effects of the addition of a triangular area ahead of the inboard part of a conventional sweptback wing. The addition of this area formed a wing with two stages of sweepback. Results were obtained for a Mach number range of 0.40 to about 0.94.

As part of a special research program recommended by the Special Subcommittee on the Aerodynamic Problems of Transonic Aircraft Design, a systematic series of wing-body combinations has been investigated in the Langley high-speed 7- by 10-foot tunnel over a Mach number range of about 0.60 to 1.18, using the transonic-bump test technique. Lift, drag, pitching moment, root bending moment, and the effective downwash angles and dynamic pressures in regions of possible tail locations were measured.

The freely falling body technique continued to be used during the past year to investigate the effects of wing sweep, taper, and thickness ratio on the zero-lift drag of a number of wing-body configurations in the transonic speed range.

The triangular-wing plan form continues to be of interest and several investigations have been conducted in the past year at transonic speeds on such plan forms.

Two downwash investigations were made in connection with the NACA transonic research airplane program. Calculations were made to determine from linearized theory the downwash at the tail of the X-1 airplane at supersonic speeds and the effect of the downwash on the elevator deflection required for trim. Detailed experimental measurements of downwash angle were made in the Langley 8-foot high-speed tunnel for a model of the D-558-I airplane at high subsonic speeds.

Wings at Supersonic Speeds

The source-distribution method for analyzing the steady flow over thin finite wings at supersonic speeds has been extended in Technical Note 1699 to permit the prediction of slowly varying, unsteady load distributions over finite wings. Similarly, the simplified method of determining lift distribution for thin three-dimensional wings of fairly general plan form has been applied to predict the load distributions for a wing in steady roll and pitch (Technical Note 1689).

The explicit evaluation of the suction forces along subsonic leading edges of a family of wings at supersonic speeds (Technical Note 1718) led to the conclusion that higher lift-drag ratios may be obtained with curved than with straight-line, plan-form boundaries.

A theoretical method was developed in Technical Note 1736 for obtaining the aerodynamic forces acting on thin wings in an irrotational nonuniform supersonic stream. In addition, the source-distribution method

was applied to estimate the properties of a ring airfoil (Technical Note 1678).

The results of the linearized theory for the loads on thin wings at supersonic speeds have been compared with experimental values obtained in the Lewis 18- by 18-inch supersonic tunnel at a Mach number of 1.9. Other experiments are being conducted to check the accuracy of theoretical methods.

Experimental studies have indicated that the optimum airfoil shape for two-dimensional supersonic flow is not necessarily that indicated from theoretical considerations based on a nonviscous flow. An investigation at supersonic speeds in the Ames 1- by 3-foot supersonic wind tunnels has indicated that principles other than those heretofore considered may lead to airfoil sections with improved characteristics.

An experimental investigation in the new Ames 6- by 6-foot supersonic wind tunnel was conducted to measure the load distribution over a 63° sweptback wing at several supersonic speeds. This investigation was part of the coordinated research program on this configuration mentioned in the preceding section. Another study of the same configuration to determine lift, drag, and moment characteristics has been carried out in the Ames 1- by 3-foot supersonic wind tunnel at a Mach number of 1.5.

An extensive investigation of triangular wings was made in the Langley 9-inch supersonic tunnel. The investigation included tests of 22 triangular wings of 2 airfoil sections and 11 apex angles at Mach numbers of 1.6, 1.9, and 2.4. One series of 11 wings had double-wedge sections and the other series had sections with elliptical leading edges.

The downwash and wake behind unswept, swept, and triangular wings have been measured at supersonic speeds in the Ames 1- by 3-foot supersonic wind tunnel No. 1. The results have been compared with available linearized theory.

Bodies and Wing-Body Interference

Analyses are being conducted to determine the load distributions and the aerodynamic characteristics of arbitrary thin bodies at supersonic speeds. An approximate method for obtaining the flow around thin arbitrary conical bodies at supersonic speed by the use of linearized theory is reported in Technical Note 1659. This method was extended to simplify the description of angle-of-attack and yaw effects. Experimental results have been obtained on an elliptic cone in an investigation conducted to check this theory. A graphical method was presented in Technical Note 1768 by which the approximate pressure distribution on a slender arbitrary body of revolution moving at supersonic speeds may be calculated with appreciable saving of time.

Experiments were conducted on an asymmetrical nonconical body to determine pressure distributions on a typical fuselage of a supersonic airplane. An attempt to estimate the theoretical loads on this body led to the discussion of three-dimensional characteristics presented in Technical Note 1849. In another investigation the method of characteristics was applied to the determination of the exact nonviscous supersonic pressure distribution around bodies of revolution at small angles of attack. The system developed considers the effect of the variation of entropy due to the curved shock and is described along with two practical methods for numerical calculation in Technical Note 1809.

An investigation was conducted in the new Langley 4- by 4-foot supersonic tunnel to determine the pressure distribution over the fuselage of a supersonic airplane model with and without canopies. Experimental results have been compared with theoretical calculations and analytical procedures have been evolved for the calculation of canopy pressure distributions.

A method has been developed for evaluating from shadow or schlieren photographs the pressure drag of axially symmetric and two-dimensional bodies operating with detached shock. The method which is described in Technical Note 1808 can be used also to determine the external drag of supersonic inlets with detached shocks and to evaluate the external shocks of perforated inlets.

The pressure drags of a blunt-nose and sharp-nose body were measured at transonic speeds by means of the wing-flow method and the results compared.

Investigations of wing-body and wing-nacelle interference at supersonic and transonic speeds have been conducted. Theoretical methods have been developed for the prediction of the mutual interference between a body and either a single wing or a cruciform wing at supersonic speeds. Two reports have been published (Technical Notes 1662 and 1897), giving the load distribution, lift, side force, pitching moment, and yawing moment for configurations of the missile type.

An experimental investigation has been conducted to study means for increasing the force-divergence Mach number of swept-wing-body combinations. A method for alleviating the adverse interference between swept wing and body was tried which involved the contouring of the fuselage sides to conform to the normal path of the streamlines of a swept wing. Theoretical calculations of the contours required were discussed in a previous annual report. A second method involving modifications to the wing-root section was also investigated experimentally.

The effects of a nacelle on the aerodynamic characteristics of a swept wing have been investigated in the Langley 16-foot, high-speed tunnel up to Mach numbers of 0.61 for the wing-nacelle combination and 0.70 for

the wing alone. The results which are published in Technical Note 1709 show that the presence of the nacelle had no effect on the lift-curve slope of the unswept wing, increased the lift-curve slope about 10 percent with the wing swept back 45° , and decreased the lift-curve slope slightly with the wing swept forward 45° . The presence of the nacelle did not appreciably alter the stalling characteristics of the 45° sweptforward and sweptback wings but caused an appreciable reduction in maximum lift for the wing in the unswept position. The drag increment due to the nacelle was generally lower for the swept configurations than for the unswept case. Addition of the nacelle to the wing reduced the longitudinal stability of all the swept wings.

The external-store problem continues to be of importance. The rocket-propelled-model technique was utilized to determine the drag increments at transonic speeds due to the presence of strut-mounted wing tanks of moderate fineness ratio on a sweptback wing.

SUBCOMMITTEE ON FLUID MECHANICS

Viscous Flows

A fundamental knowledge of boundary-layer phenomena at high speeds has assumed increasing importance to the aerodynamicist. During the past year a study was made of the behavior of the laminar boundary layer in compressible flow, following procedures evolved previously for the incompressible case; the results were reported in Technical Note 1805. Theoretical considerations indicate that with the usual assumptions of boundary-layer theory the separation point of the steady compressible laminar boundary layer is independent of Reynolds number when the Mach number, the gas properties, and the velocity and temperature profiles do not change with Reynolds number. For the same conditions the boundary-layer thickness is inversely proportional to the square root of the Reynolds number. Separation of the laminar boundary layer occurs only when the static pressure along the surface rises in the direction of the flow.

The flow over the blunt base of bodies and over blunt trailing edges of wings is important from drag considerations in supersonic flow. As a fundamental approach to these problems an analytical study was made of the phenomena of laminar mixing in a compressible fluid and reported in Technical Note 1800. Detailed velocity profiles were computed for free-stream Mach numbers from 0 to 5.0. The effect of various assumptions for the change of viscosity with absolute temperature was considered.

The free turbulent mixing of a supersonic jet of Mach number 1.6 has been experimentally investigated and the results have been reported in Technical Note 1857. An interferometer was used in the investigation to measure

density and velocity distributions through the mixing zone. Velocity distribution was found to be similar to the distributions for incompressible jets only over the subsonic part of the mixing region.

An investigation was undertaken to study certain interference effects arising from tunnel-wall boundaries in airfoil investigations at supersonic speeds. The results of the investigation indicate that for airfoil models mounted from the wall of a supersonic tunnel large pressure disturbances over parts of the model can result from shock-wave propagation into the stream due to a thickened tunnel-wall boundary layer at the model location.

Compressible Flows

The results of a study of the subsonic flow past an infinitely long corrugated circular cylinder are presented in Technical Note 1850 to show the relation between two-dimensional and three-dimensional axisymmetrical flow. A solution is obtained which contains as limiting cases both the Prandtl-Glauert correction for two-dimensional flow and the Gothert correction for the flow past slender bodies of revolution. Included also are velocity-correction formulas for a cylinder with a single bump and for a corrugated cylinder in the presence of walls.

In connection with the use of the hodograph method of treating plane potential compressible flows, various hypergeometric functions that arise as particular solutions of Chaplygin's differential equation have been tabulated in Technical Note 1716. These tables should prove useful in the tabulation of other auxiliary functions arising in various compressible-flow problems.

A number of investigations have been made by several educational institutions, under contract to the NACA, relative to the theory of compressible flows past two-dimensional airfoils. Among these investigations was a study made at Harvard University of the supercritical flow past an NACA 0012 airfoil (Technical Note 1746). Relaxation methods were employed to calculate the pressure distribution, and the results were observed to agree qualitatively quite well with experiment. In a contract investigation by Brown University, reported in Technical Note 1875, the application of the method of operators to the study of two-dimensional compressible flows was extended to the case of supersonic flow patterns.

The analytical methods that appear to be best suited for the treatment of two-dimensional supersonic flows with detached shocks have been reviewed in Technical Note 1858. A short discussion of the application of the methods regarded as reliable in the transonic range is included.

Interest has increased recently in the theory and application of unsteady flows. Experimental measure-

ments and theoretical calculations have been made for unsteady flows in passages of constant cross-sectional area. The flow considered included expansion zones, discontinuous compression fronts, temperature contact discontinuities, and reflections and interactions of these quantities. Agreement of experimental pressure-time measurements and discontinuity position and configuration with the theory is very good.

An extended point-by-point method has been developed and described in Technical Note 1878 for the calculation of unsteady flows through tubes with variable cross sections containing strong shocks and large temperature contact discontinuities. Calculations were made of the flow pattern created by the bursting into a vacuum of a diaphragm at the minimum section of a supersonic nozzle.

Gas Dynamics

The extreme altitudes at which sounding rockets and missiles operate have introduced a new field of fundamental aerodynamic research. At these altitudes the air must be considered as composed of individual molecules rather than as being a continuous medium. New facilities have been put into operation for exploring the phenomena encountered in very low density flows. Difficult problems of technique have been encountered in the design of these facilities and the greater part of the effort to date has been concentrated on the development of research methods. One example of these problems is in the visualization of low-density flows. At very low densities the schlieren technique for flow visualization becomes impracticable or impossible. A new and promising method of flow visualization has been investigated and reported in Technical Note 1900, in which the phenomenon of afterglow was utilized.

A preliminary investigation of free-molecule flow about transverse wires has been undertaken. Heat-transfer and drag measurements have shown good agreement with free-molecule theory.

Theoretical research on low-density flows has also been conducted during the past year. Calculations have been made using the methods of kinetic theory of the temperature rise of uncooled flat plates traveling at high speeds in the upper atmosphere. These calculations were reported in Technical Note 1682. A method was derived in Technical Note 1821 by means of which pressure measurements obtained behind an orifice on a rapidly moving object may be used to determine the ambient-air pressure. A comparison of the results obtained by this method and that which considers the gas to be a continuum shows the method based on the fluid concept to be in error at altitudes which are attainable with modern rockets.

An approximate method has been developed for the extension of the properties of the incompressible lami-

nar boundary layer on a flat plate into the slip-flow region, using Karman's momentum method. At equivalent stations on the same body at the same Reynolds number the total thickness and the skin friction of a slipping boundary layer are less than those of the normal boundary layer. The difference between the slip and the normal boundary layer is small until slip velocities at the wall become about one-third of the free-stream velocity.

Very high supersonic wind-tunnel Mach numbers for aerodynamic investigations are obtained by acceleration of the air by means of a pressure difference so that the random kinetic energy of the molecules is converted into kinetic energy in the wind-tunnel test section. For very high Mach numbers high stagnation temperatures and pressures may be required which introduce effects of vibrational heat capacity and of molecular forces and size such that the perfect gas law and the assumption of constant heat capacity may no longer be sufficiently accurate. Errors in using the perfect gas law and the assumption of constant heat capacity have been evaluated. The variation of heat capacity is accounted for by quantum mechanical considerations and the effects of molecular forces and molecular size are accounted for by use of van der Waals' equation.

In the operation of supersonic wind tunnels in general, the condensation of moisture in the air stream is an important consideration because the formation of a condensation shock distorts and modifies the flow and should therefore be avoided. A study has been made of the limiting conditions under which a condensation shock will form.

Aerodynamic Heating and Heat Transfer

Because of aerodynamic heating the operation of aircraft at high speeds is dependent on the provision of adequate insulation and cooling systems or on keeping the time of high-speed flight short. Calculation of surface temperatures and the design of cooling systems are dependent on adequate heat-transfer data and on a body of theory by which the data may be correlated and application of the data extended. Experiments have been conducted during the past year to determine heat-transfer coefficients at supersonic speeds. During the course of this experimental work comparisons were made with certain theoretical results which indicate a stabilization of the laminar boundary layer when the direction of the heat flow is from the boundary layer to the surface.

Experimental results have indicated that heat-transfer theories that assume a constant surface temperature are in some respects inadequate. A general theory has been developed by means of which temperature and velocity profiles, heat transfer, and skin friction can be calculated for laminar boundary layers on a two-dimen-

sional or axially symmetric surface without pressure gradient but with an arbitrary distribution of surface temperature.

A small supersonic wind tunnel designed expressly for the investigation of heat transfer and related phenomena has been placed in operation during the past year. This tunnel is of the variable-density type which enables a large Reynolds number range to be obtained, and has special provisions for assuring constant air temperature and a low turbulence level. An investigation has been undertaken in which temperature-recovery factors have been measured in the laminar, transition, and turbulent boundary-layer regions of an insulated flat-plate model.

An investigation was conducted at the California Institute of Technology, under contract with the NACA, to study the flow and heat transfer in a heated turbulent air jet. Measurements were made of the total pressure and temperature fields in a round turbulent jet with various initial temperatures, and the results have been published in Technical Note 1865. One result was that the jet spreads more rapidly as its density becomes lower than that of the surrounding medium. Data on shear stress and heat-transfer distributions were obtained from these experiments.

SUBCOMMITTEE ON STABILITY AND CONTROL

Longitudinal Stability

To determine the static longitudinal stability characteristics of complete models with swept wings at low speeds, an investigation was conducted in the Langley 300-mph 7- by 10-foot wind tunnel. The longitudinal stability characteristics with flaps deflected and retracted were obtained for models having wings with 0°, 15°, 30°, and 45° of sweepforward and sweepback. In addition, the effect of horizontal-tail location on the longitudinal stability characteristics of a series of wing and tail combinations was investigated. Similar tests were conducted at larger scale in the Langley 19-foot pressure tunnel for a 42° and a 52° sweptback wing. Results of these investigations were compared with available theoretical and empirical methods for predicting longitudinal stability characteristics.

Downwash and dynamic-pressure characteristics behind various swept wings have been investigated. The results, including the aerodynamic-force characteristics of the wings, have been reported in Technical Note 1703. It was found, for the range of configuration investigated, that a low tail position provided the most satisfactory stability characteristics. The center line of the wake was found to be located in a higher position for the sweepforward wings than for the sweptback wings.

Other investigations of wing wake have included measurements of both downwash and sidewash behind a 42° sweptback wing and an analytical study of the wake of a triangular wing. This latter research has been reported in Technical Note 1803. A method previously developed was applied to calculate downwash in both vertical and horizontal planes of symmetry.

The effects of propeller operation on the static longitudinal stability of single-engine tractor monoplanes have been investigated at the Langley Laboratory and a method has been developed for computing power-on pitching moments. The results of these studies are presented in Technical Note 1722. The method developed to compute the power-on pitching-moment curves evolved from a study of results of 28 wind-tunnel powered-model investigations and permits predictions of power-on longitudinal stability characteristics that are in good agreement with experimental results.

The effects of tail length and tail volume on the longitudinal stability characteristics of a powered model of a propeller-driven low-wing single-engine airplane were investigated at the Langley Laboratory. The results, presented in Technical Note 1766, show that the destabilizing shift in the neutral point caused by power effects increases with increasing tail length or increasing horizontal-tail area.

Severe diving tendencies experienced on straight-wing conventional aircraft at supercritical speeds have been investigated at the Ames Laboratory. These diving tendencies have been attributed in a large part to the increase in angle of attack required to maintain a constant lift coefficient as the speed increases.

Tests at the Ames Laboratory of two airplanes employing different airfoil sections were conducted to determine the effect of airfoil modifications on the longitudinal stability characteristics at supercritical speeds. Contributions of the various airplane components to the static longitudinal stability of the airplanes were determined.

For certain supersonic speed ranges, design studies have indicated that a thin sharp-edged wing without sweep would have better performance characteristics than other wing arrangements. The Ames 12-foot low-turbulence pressure wind tunnel has been used for investigation of an airplane configuration utilizing a wing of this type at high subsonic speeds. In addition to basic studies of the wing and fuselage combination, various locations of the horizontal tail were investigated. The results indicate that, at least for one general arrangement, there are no erratic effects of compressibility on the longitudinal characteristics of the model up to the highest Mach number investigated. In addition, the effects of leading- and trailing-edge wing flaps were investigated to determine the maximum lift characteristics of the configuration.

Lateral and Directional Stability

Lateral- and directional-stability problems, like the longitudinal-stability problems, have multiplied and assumed new importance with the increases in aircraft speeds and the resultant changes in configurations.

Investigations of complete model configurations have included a low-speed study of the static lateral stability characteristics of a 52° sweptback wing. This investigation conducted in the Langley 19-foot pressure tunnel was undertaken to study the effects of Reynolds number, leading-edge flaps, and wing-fuselage combination on the lateral stability characteristics. The static and rolling stability characteristics of triangular-wing models having various aspect ratios, airfoil sections, and vertical-fin arrangements have also been investigated at the Langley Laboratory. The effects of tail length and tail volume on the lateral stability characteristics of a powered model of a single-engine propeller-driven low-wing airplane have been reported in Technical Note 1766, previously mentioned. This report shows that the increase in directional stability caused by power becomes larger as the tail length is increased. The results also show that the tendency toward rudder lock decreases in the positive yaw range as the tail length increases, but is unaffected in the negative yaw range.

Calculations of lateral-stability derivative were made for a group of wing plan forms suitable for supersonic flight. Technical Notes 1700 and 1850 present the results for the rolling moment due to sideslip and the yawing moment due to sideslip, respectively.

An investigation to determine the effects of thickness on the lateral force and yawing moment of sideslipping triangular wings was conducted at the Langley Laboratory. This investigation was based on linearized supersonic-flow theory and the results are presented in Technical Note 1798. In this investigation, it was found that the contribution of wing thickness to the values of the lateral-force and yawing-moment stability derivatives is small in comparison with the effects to be expected from a vertical tail. However, for some designs, the contribution of wing thickness to the yawing-moment derivatives can be appreciable.

The effect of varying the yawing moment due to rolling over a wide range of values on the lateral oscillatory stability characteristics of a typical swept-wing fighter has been investigated. The airplane loading conditions were also varied to simulate an airplane with and without wing-tip fuel tanks. Results of this investigation, presented in Technical Note 1723, show that increasing the yawing moment due to rolling in a positive direction increases the damping of the short-period oscillation. For any given value of yawing moment due to rolling, the addition of the wing-tip tanks decreased the damping of the short-period mode.

A theoretical investigation was undertaken to develop a simplified expression for the neutral-lateral-oscillatory-stability boundary. The results of this study are reported in Technical Note 1727. The investigation shows that, for particular combinations of the mass and aerodynamic parameters, two neutral-oscillatory boundaries exist, corresponding to the high- and low-frequency modes of motion of the airplane. Simple test functions were derived which, if satisfied, indicate that these expressions may be used to approximate the neutral-stability boundary. The results obtained by the simplified expression are in good agreement with the results of more exact calculations.

A study was made of the lateral oscillatory mode of motion to determine a boundary which defines satisfactory relationships between the period and damping of this mode of motion for a given criterion. This analysis reported in Technical Note 1859 resulted in the development of a method which can define the relationship between period and damping for a given set of requirements. The report also presented a method by which curves representing a constant rate of spiral divergence may be constructed. The methods presented in this report are applicable to both lateral- and longitudinal-stability analyses.

The effects of various design parameters on the lateral-stability characteristics of a glider pulled by a single towline were experimentally investigated in the Langley free-flight tunnel. The effects of varying effective dihedral, directional stability, relative density, towline-attachment location, and towline length were determined from model flight tests. The results of this investigation show that it is possible to obtain lateral stability with a single towline. An approximate theoretical analysis was also made and the results compared with the model-flight-test results. The theory predicted the existence of divergence and the periods of lateral oscillations with fair accuracy although the theoretical damping values were too conservative to be of much practical value.

Rotary Stability Derivatives

Before calculations of the dynamic-stability characteristics of an aircraft can be made, the rotary-stability derivatives of the design must be known. The range of values of these derivatives and their relative importance have been greatly affected by changes in aircraft configuration. Research studies of these derivatives (yawing, rolling, and pitching) have been continued by the NACA laboratories with much of the low-speed experimental work being conducted by the use of the rolling and curved-flow facilities of the Langley stability tunnel.

Rotary-derivative investigations in the Langley stability tunnel have covered pitching derivatives of

wings, effects of airfoil section on rolling and yawing derivatives, effect of addition of wing-leading-edge slats on the derivatives of swept and unswept wings, and rolling stability derivatives of a series of thin sweptback wings. The results of an experimental investigation of the effect of geometric dihedral on the rolling stability derivatives are presented in Technical Note 1732. A comparison of these data with current methods of calculation indicates the effects of geometric dihedral can be predicted with fair accuracy.

Empirical corrections to the theoretical values of the yawing moment resulting from rolling are presented in Technical Note 1835. These corrections were developed from experimental data and have been found to be generally reliable over a wide range of lift coefficient.

A stability-tunnel investigation of the additional spanwise wing loading caused by rolling has been reported in Technical Note 1839. The wings investigated covered a range of aspect ratio, sweep angle, and taper ratio. These data can be used to determine the damping-in-roll due to sideslip for wings with dihedral. It has been found that the values of the derivative obtained by applying the above data are more reliable than values obtained by strip theory.

Several methods for predicting the damping-in-roll of wings through the lift-coefficient range have been investigated and are reported in Technical Note 1924. One method, in which the damping-in-roll at zero lift coefficient was modified only in accordance with variations in finite-span lift-curve slope, was found to be almost as reliable as the complete method in which all known factors are accounted for.

An analytical investigation was made to derive a method for modifying existing correction factors for lifting-surface theory to account approximately for the effects of sweep. These factors, reported in Technical Note 1862, have been applied to existing lifting-line theories for damping-in-roll of swept wings. The resulting formulas are simple and calculated results are in good agreement with low-speed experimental data. If the Glauert-Prandtl transformation is used, the formulas are applicable to swept wings at speeds below the critical.

Analytical investigations have been made of the effects of compressibility at subsonic speeds on the stability derivatives. Formulas based on semiempirical concepts are given in Technical Note 1854 for making compressibility corrections to the static and rotary derivatives of wings.

To obtain damping-in-roll data at high speeds, an investigation employing the free-roll technique was conducted in the Langley high-speed 7- by 10-foot tunnel. The investigation covered a series of sweptback

wings of various aspect ratios. Data were obtained for Mach numbers up to about 0.91.

Further high-speed data on damping-in-roll characteristics were obtained on a sweptback configuration that was twisted linearly to represent the rolling wing. Tests were made at Mach numbers between 0.6 and 1.15 in the Langley high-speed 7- by 10-foot tunnel using the transonic-bump technique and at a Mach number of 1.9 in the Langley 9- by 12-inch supersonic blow-down tunnel. The effects on the damping-in-roll characteristics of thickening the trailing edge of the aileron were also determined.

The Langley stability analysis section has developed theoretical values of the stability derivatives at supersonic speeds for thin, flat, rectangular wings without dihedral. The results of this study are presented in Technical Note 1706. A linearized theory was used in this study which presents the value of the derivatives for steady and accelerated vertical and longitudinal motions and for steady rolling, yawing, sideslipping, and pitching velocities. These data are limited to Mach numbers and aspect ratios greater than those for which the Mach line from the leading edge of the tip section intersects the trailing edge of the opposite tip section.

An analysis of the stability derivatives for a series of sweptback wings with sweepback and sweepforward of the trailing edges has been made using the pressure-distribution data presented in Technical Note 1572. The derivatives were formulated for a range of angle of attack, sideslip, vertical acceleration, pitching, rolling, and yawing. The results of the investigation, presented in Technical Note 1761, are limited to Mach numbers for which the wing is wholly contained between the Mach cones from the leading and trailing edges of the center section of the wing.

A theoretical evaluation has also been made of the lift and damping-in-roll of a series of thin sweptback wings of arbitrary taper and sweep. This analysis is presented in Technical Note 1860 and is based upon linearized supersonic-flow theory. The results are valid for a range of supersonic speed for which the wing is wholly contained between the Mach cones from the leading and trailing edges of the center section of the wing. A series of design charts is presented which permits rapid estimation of the lift-curve slope and damping-in-roll derivatives.

A preliminary experimental investigation to determine the damping-in-roll of several rectangular and triangular wings has been conducted in the Langley 9-inch supersonic tunnel.

Controls

Considerable research is being undertaken on control problems because control characteristics, both

static and dynamic, are of great importance in aircraft and missile design.

An analytical and experimental investigation of the effect of plan-form changes on the lift and hinge-moment characteristics of control surfaces has been made at the Ames Laboratory as a continuation of an extensive control program. The systematic experimental results obtained in this investigation have been compared with various theories for predicting lift and hinge-moment parameters for the conventional and sweptback plan forms investigated. This comparison indicated a method of prediction sufficiently accurate for preliminary design purposes.

A flight investigation was conducted on an airplane equipped with an all-movable horizontal tail having a control system incorporating the combination of geared unbalancing tabs and servotabs. The results of this investigation are reported in Technical Note 1763. The basic system offered the possibility of having a constant control-force gradient regardless of altitude or airplane center-of-gravity position, but was found to be unsatisfactory when rapid elevator deflections were required because of light stick forces. Flights made with the system modified to increase the stick force for rapid control application (while maintaining low control forces for gradual maneuvers), in conjunction with an all-movable horizontal tail or a conventional elevator, indicated that satisfactory stick-force gradients for any maneuver were provided.

As part of the lateral-control program at the Ames Laboratory, high-speed tests of lateral controls of a swept wing with fences to improve the low-speed stalling characteristics indicated that the particular fences investigated will have no appreciable effect on the high-speed control characteristics.

The lateral-control characteristics of several aileron configurations investigated in the 300-mph 7- by 10-foot tunnel at the Langley laboratory have been reported in Technical Note 1738. This report presents the results of the effects of varying trailing-edge angle and control span on the rolling effectiveness, lift effectiveness, and control hinge moments. It was found that, for the thinner trailing-edge angles, theoretical methods for predicting control effectiveness were satisfactory. However, the agreement between experiment and theory was poor for the large trailing-edge angles. The effectiveness of 20-percent-chord half-span ailerons and high-lift and stall-control devices on three swept wings has been investigated at high Reynolds number in the Langley 19-foot pressure tunnel. The effects of airfoil trailing-edge shape on aileron effectiveness at high-subsonic Mach numbers have been investigated in the Langley 8-foot high-speed tunnel. The results of this investigation are presented in Technical Note 1596.

Auxiliary types of lateral controls have been investigated in the Langley 7- by 10-foot tunnel. One investigation included the study of segmented plug ailerons extending from the 20-percent-span station to the 80-percent-span station of a 42° sweptback wing. The segments were mounted normal to the free-stream flow. The basic aileron and the aileron with several modifications were investigated for a range of spoiler projection for various angles of attack. The plug aileron was also tested in conjunction with a full-span slotted flap.

The results of the investigation of plug ailerons on a thin low-drag straight wing in conjunction with a full-span slotted flap are reported in Technical Note 1802. The investigation, which covered the range of Mach number from 0.13 to 0.61 indicated that the plug-aileron configuration developed would be suitable for lateral control in conjunction with full-span slotted flaps. The effectiveness of the plug aileron increased with increasing Mach number and Reynolds number. The variation of rolling moment with aileron projection was fairly linear. The rolling effectiveness was greater with the flap deflected than with the flap retracted.

Another unswept wing with 15-percent-thick airfoil sections was investigated with both plug and retractable ailerons in conjunction with a full-span slotted flap. The results of this investigation are presented in Technical Note 1872. The study indicates that large increases in lift can be obtained by use of full-span slotted flaps and that, in a certain deflection range, the flaps can be used to advantage as a glide-path control. It was found that the plug aileron was generally more effective than the retractable aileron, but that both were effective roll controls. The yawing moments produced by the ailerons were generally favorable with the flap retracted, becoming less favorable with increasing angle of attack or flap deflection.

To investigate the low hinge-moment characteristics of spoilers, tests were made of an unswept wing with an aspect ratio of 3.

An investigation was made in the Langley two-dimensional low-turbulence pressure tunnel to determine the effectiveness of a lateral-control device for a wing equipped with a full-span double-slotted flap. The rear portion of the flap was hinged in the manner of a conventional Frise aileron, and the lip of the double-slotted flap acted as a slot-lip aileron. This study showed that the lift effectiveness of the slot-lip aileron increased with increasing flap deflection. In general, the results indicate that a slot-lip aileron can be combined with a trailing-edge Frise aileron on a full-span double-slotted flap to provide satisfactory lateral-control characteristics with large flap deflections.

The Langley low-turbulence tunnel section also investigated a two-dimensional airfoil equipped with a

sealed internally balanced control surface in conjunction with a leading tab. Results of this study indicate that the use of a leading tab will result in large increments in lift effectiveness for a range of tab-flap deflection ratio.

To permit the intelligent selection of aerodynamic brakes, the drag characteristics of various brakes as measured in flight and in wind tunnels have been collected and summarized. Calculation procedures and graphs have been prepared that simplify the determination of the speed-altitude-time relationship for airplanes equipped with aerodynamic brakes in various specified maneuvers.

A wind-tunnel investigation was conducted in the Langley 300-mph 7- by 10-foot tunnel to determine the characteristics of ailerons used as speed brakes or glide-path controls. The tests were made on an NACA 65-210 wing and an NACA 65₂-215 wing equipped with full-span slotted flaps. Several plug-aileron and retractable-aileron configurations were investigated at Mach numbers between 0.13 and 0.71. The results indicate that plug or retractable ailerons, either alone or in conjunction with wing flaps, are very effective as speed brakes or glide-path controls.

The effectiveness of the horn-balanced flap in reducing hinge moments at high-subsonic and transonic speeds has been investigated, respectively, in the Langley high-speed 7- by 10-foot tunnel and by the wing-flow method. The investigation in the 7- by 10-foot tunnel was made with a 45° sweptback wing while the wing-flow-method study employed a 35° sweptback wing.

The effect of trailing-edge thickness on the high-subsonic and transonic characteristics of an aileron on a 42.7° sweptback wing has been investigated in the Langley high-speed 7- by 10-foot tunnel.

The transonic-bump technique has also been used to determine the lateral-control characteristics of 30-percent-chord plain flaps of various spans. The wing used in this study had 45° of sweepback and an aspect ratio of 4. The rolling, pitching, and lift characteristics attributable to control deflection were determined.

The influence of spanwise position and size of the ailerons on the control characteristics was investigated at transonic speeds. The investigation was made by means of a coordinated study of wind-tunnel results (transonic bump) and results obtained with free-flight rocket models.

General investigations of the effectiveness of wing controls have been continued by the use of simple rocket-propelled free-flight models with the object of developing controls satisfactory for flight at transonic and supersonic speeds. The data were obtained at almost full-scale Reynolds numbers. As part of the investi-

gations, the rolling effectiveness of simple trailing-edge ailerons, in conjunction with a series of wings differing in sweep and airfoil section, was determined.

One type of wing currently believed suitable for flight at supersonic speeds is the thin unswept wing of moderate aspect ratio. Accordingly, a rocket-propelled-model investigation of the rolling effectiveness of a typical wing of this type having outboard trailing-edge ailerons has been undertaken.

To obtain the supersonic control characteristics of wing-body combinations, two wings of different plan form were tested as all-movable surfaces and as fixed surfaces in the presence of a half fuselage at a Mach number of 1.9 in the Langley 9- by 12-inch supersonic blow-down tunnel. One wing had a triangular plan form with 60° leading-edge sweep and the other a rectangular plan form modified by an Ackeret type tip.

A hinge-moment investigation was conducted in the Langley 9-inch supersonic tunnel to determine the feasibility of interconnecting leading- and trailing-edge flaps for the purpose of reducing control hinge moments.

Experimental research on the effectiveness of controls at transonic and supersonic speeds has shown that the thickness ratio of both airfoil and control surface has important effects on control power. A study was conducted to determine the effect of thickness ratio on control effectiveness. Results of this study are presented in Technical Note 1708. The method developed employed the Busemann third-order approximation for two-dimensional isentropic flow (which incorporates the effects of thickness) with three-dimensional solutions found by the use of linearized theory.

Other investigations have emphasized that, particularly at supersonic speeds, large twisting moments are imposed on a wing by deflection of a trailing-edge control. Hence, the torsional stiffness required of supersonic wings to prevent aileron reversal is much greater than that required of subsonic wings. A study of wing twisting moment imposed by trailing-edge ailerons on unswept and untapered wings—and the resulting wing twisting and accompanying loss of rolling effectiveness—has been theoretically treated for the supersonic case and the results have been reported in Technical Note 1769. The results of an analysis on tapered unswept wings are presented in Technical Note 1890.

A study was made to determine the possibility of utilizing the principle of a sealed internal-control-surface balance as a means of reducing control-surface hinge moments at subsonic and supersonic speeds.

Automatic Control

Research on automatic controls has been greatly expanded—not only because of the increased interest in

the field of guided missiles but also because of the interest in automatic-control applications to airplanes. Studies of some current and projected airplane designs indicate that their flying qualities can be improved through the use of automatic devices.

As part of an investigation of control systems for target-seeking missiles, a study has been made in the Langley free-flight tunnel to determine the automatic lateral stability of a flying model equipped with a gyro stabilizing unit which applied control in response to bank and yaw. Free-flight tests were made with a flicker-type control system installed in the model and with this system modified to produce a hunting control which effectively gave proportional response. The effects of varying the cant angle and rudder deflections were investigated.

The normally small-size, high-velocity, and high-maneuverability requirements of guided missiles necessitate automatic stabilization systems possessing exceedingly rapid response characteristics. The Langley Laboratory is studying the factors limiting the response of basic types of automatic stabilization systems and the relevant aerodynamic characteristics of automatically stabilized missiles in an endeavor to achieve the necessary response characteristics. In consequence, an analysis and a ground investigation of an automatic stabilization system were undertaken. These studies included a general analysis of a system incorporating both displacement- and rate-sensitive gyroscopes. From the data obtained, design charts have been prepared which permit the rapid determination of the stabilization characteristics that may be expected from this system.

The Langley stability analysis section has made a theoretical investigation to determine the effect of automatic stabilization on the lateral oscillatory stability of a hypothetical airplane at supersonic speeds. The investigation included consideration of the effectiveness of an automatic pilot sensitive to a displacement in either yaw or roll and of an automatic pilot sensitive to either the yawing or rolling angular velocity. The calculations assumed an idealized control system without lag. The results of the investigation, presented in Technical Note 1818, indicated that, whereas all the automatic pilots improved the stability of the short-period oscillations, the greatest improvement was obtained for an automatic pilot sensitive to the yawing angular velocity and geared to the rudder so that rudder control is applied in proportion to the angular velocity.

Flying Qualities

The increases in speed of flight, made possible by recent power-plant developments, have dictated radical changes in aerodynamic design which, in conjunction with the mass characteristics of current and proposed aircraft, have necessitated extensive studies of the

dynamic handling- or flying-quality characteristics of these designs.

The effect of variation of the aerodynamic characteristics on the dynamic lateral stability characteristics of an airplane in flight has been investigated at the Ames Laboratory. A method of automatically varying the static lateral stability derivatives in flight was devised to isolate the effects of changes in the derivatives from those resulting from other influences—such as air gustiness and piloting technique. The results of flight tests made with the automatic equipment installed have demonstrated the practicability of the system (Technical Note 1788). This method of varying the aerodynamic derivatives appears to offer great promise, both as a means for determining the optimum stability characteristics desired by pilots and also as a method for improving the stability characteristics of existing airplanes.

Flight tests of an airplane having a 35° sweptback wing have been completed. The results of the investigation are reported in Technical Note 1743, which presents the lateral and directional stability and control characteristics of the airplane with and without an 80-percent-span slot and with and without a ventral fin. This flight investigation showed that the directional stability of the airplane was positive in all conditions but was reduced to an undesirably low value at high lift coefficients with the ventral fin removed. The pilot considered a slight negative dihedral effect, present at low lift coefficients, more objectionable than a high positive dihedral effect present at high lift coefficients. The longitudinal stability with an 80-percent-span slot on the wing and with the flaps neutral was high throughout the speed range. With the flaps down, the longitudinal stability became neutral or slightly negative near the stall. The stalling characteristics of the airplane were considered good when the 80-percent-span slots were used.

The Langley pilotless aircraft research division—using rocket-propelled models in free flight—has obtained extensive aerodynamic and flying-quality data for a tailless triangular-wing airplane.

At present, flying-quality characteristics can be generally compared with specific quantitative requirements except for stall warning and the behavior of the airplane in the complete stall. In order to provide a preliminary basis for a quantitative evaluation of the stall-warning characteristics of an airplane, a study has been made at the Ames Laboratory correlating pilots' opinions of stall-warning properties of 16 airplanes with a number of the quantitative factors producing the warning. The results of this study, reported in Technical Note 1868, indicate the quantitative ranges over which satisfactory stall warning occurs for preliminary rolling motion, buffeting, and rearward travel of the control

stick. It was found that the degree of buffeting and rearward movement of the control stick considered satisfactory as a stall warning was influenced by the magnitude of the rolling velocity in the complete stall.

Spinning

As have many of the other design factors, spinning characteristics of aircraft have been affected by changing aerodynamic and mass characteristics. Investigations of spinning problems have been conducted for the most part in the NACA free-spinning tunnel at the Langley Laboratory.

The results of an analysis of antispin fillets are presented in Technical Note 1779. It was found that action of the fillets is such as to increase the damping effectiveness of the fuselage area below the fillets, thus tending to prevent spin. An investigation of dorsal fins, in conjunction with this project, shows that the dorsal fins investigated had little effect on the spin and recovery characteristics. An investigation of the effect of tail length on spin-recovery characteristics was completed and the results of the investigation were presented in Technical Note 1764. It was found that a model with a long tail length had better recovery characteristics than a model with a short tail length where the models had comparable values of tail-damping power factor or even when the damping factor for the short-tail model was greater.

The spinning characteristics of a twin-tail, low-wing personal airplane were investigated. Results of this investigation (Technical Note 1801) indicated that when the rudders and ailerons were interconnected full deflection of the controls against a spin would result in satisfactory recovery. The results also indicate that when an independent rudder-aileron system is employed—with the up-aileron movement limited to a very small deflection and a rudder deflection which maintained the outboard rudder near neutral—the model would be incapable of spinning.

As in previous years, spin-recovery investigations have been conducted for a number of military-airplane design configurations.

In connection with spinning studies several emergency recovery devices have been investigated. The results of an investigation made with a dynamic model having a reaction rocket attached to the inboard wing tip and fired rearward to provide a yawing moment against the spin are presented in Technical Note 1866. Spins were terminated rapidly, indicating that a properly selected jet-reaction device is an effective method of spin recovery in an emergency.

Results of tests of spin-recovery parachutes have been reported in Technical Note 1869. These data indicate that parachute-opening characteristics are improved by increasing relative shroud-line length, tacking of "float-

ing" hem lines to prevent pulling out under load, or providing a strip of low-porosity fabric around the canopy in the area immediately above the hem line. These design alterations did not affect the drag characteristics of the parachutes appreciably, although the strip of low-porosity fabric just above the hem line had a slight adverse effect on their stability characteristics. It is indicated that for a given parachute increased airspeeds generally impair opening characteristics, decrease the drag coefficient, and improve stability.

A method for estimating the diameter of the spin-recovery parachute has been devised. Correlation with test data indicates that the method will provide satisfactory estimations of the minimum-size parachute required. A method for determining approximate shock load associated with rapid opening of the parachute has also been developed.

Specific Design Studies

In addition to the many generalized studies of stability and control undertaken at the laboratories, specific studies of component parts or complete configurations of currently interesting designs were made. Pilotless and piloted aircraft and special research designs have been included in these studies. These investigations have provided important design information, as well as useful research data.

The NACA, in cooperation with the United States Air Force and the Bureau of Aeronautics, Department of the Navy, continued transonic-flight investigations of full-scale aircraft at the Muroc Air Force Base. The X-1 and D-558-II airplanes were flown repeatedly at supersonic speeds, and a large number of successful flights were made with other research airplanes. These investigations have extended the knowledge of phenomena encountered in the high-subsonic, transonic, and low-supersonic flight regimes and have contributed to the correlation of aerodynamic data obtained through the use of other research techniques.

During the past year, the longitudinal stability of the D-558-1 airplane in accelerated flight has been investigated and the buffet boundary has been determined. The dynamic lateral stability and the approach and landing characteristics of the airplane have also undergone investigation.

Measurement of the general aerodynamic characteristics and aileron effectiveness of the X-1 airplane was continued. Data have also been obtained for rudder-fixed aileron rolls, during glides, at high Mach numbers. Some of the longitudinal stability and control characteristics of the X-1 airplane configuration were determined also by the free-fall-model technique. In this investigation, the elevator was automatically controlled so that it produced a constant value of normal acceleration throughout the speed range of the drop.

As one phase of the research-airplane program, a series of wind-tunnel tests was made of a scale model of a high-speed airplane to determine the static lateral and longitudinal stability characteristics at low- and high-subsonic Mach numbers. The study included measurements of the effectiveness of wing flaps, horizontal tail, and ailerons as well as measurements of the forces and moments acting on wing-tip ram jets and auxiliary fuel tanks. Pressure distributions on the wing and fuselage were also obtained.

A low-speed investigation was made in the Langley 300-mph 7- by 10-foot tunnel of a scale model of an airplane having a 38.7° sweptback wing and conventional tail surfaces. The investigation—the results of which are presented in Technical Note 1742—was conducted with several wing-leading-edge and tail configurations to determine the low-speed stability and control characteristics. A good correlation of wing-fuselage interference effect on effective dihedral was obtained between data for the test model and other American and German data.

Using rocket-propelled models in free flight, the pilotless aircraft research division of the Langley Laboratory conducted tests on a supersonic airplane configuration at speeds varying from subsonic to low supersonic. These tests were made to determine the general aerodynamic characteristics and stability and control characteristics of the airplane configuration. A similar model was tested by the wing-flow method at the Langley Laboratory to determine the longitudinal stability and control characteristics at transonic speeds.

An investigation of a semispan model of a tailless-airplane design was conducted in the high-speed 7- by 10-foot wind tunnel at the Langley Laboratory. The results were compared with the results of sting-mounted complete-model tests and the results of semispan-model tests (wing-flow method), thus providing a check on the various techniques.

An analysis of the estimated flying qualities of a tailless airplane, having a 35° sweptback wing, over a high-subsonic speed range has been made at the Langley Laboratory. This laboratory has also investigated the stability and control characteristics of a scale model of a tailless glider having a 43° sweptback wing.

The Langley Laboratory has conducted investigations on several unconventional aircraft configurations. One investigation was concerned with the flight characteristics of a canard configuration (tail first) at transonic and supersonic speeds. Another investigation was concerned with the determination of the static longitudinal stability and control characteristics of a model of a convertible-type airplane with rigid and articulated propellers.

Investigations of triangular wings have shown this particular plan form to have certain aerodynamic ad-

vantages. Studies of the dynamic lateral stability characteristics of a specific airplane configuration employing a triangular wing were made. These studies included determination of the neutral-lateral-oscillatory-stability boundary, the period and time to damp to one-half amplitude of the lateral oscillation, and the time to damp to one-half amplitude for the spiral mode for a range of lift coefficient and altitude.

SUBCOMMITTEE ON INTERNAL FLOW

Efficient handling of the large volumes of air required by aircraft employing turboprop, turbojet, ram-jet, or related propulsion systems is a prime consideration in efficient aircraft design. To aid in maintaining an effective internal-flow research program, the Subcommittee on Internal Flow has constantly reviewed the problems in this field. Some of the recent activity of the laboratories of the NACA and pertinent results of investigations, in the field of internal flow, follow.

Air Inlets

Work has been under way at both the Langley and Ames Laboratories to supply design data for air intakes suitable for the turbine-propeller type of power-plant installation. In recent studies of cowl inlets with propellers operating, the effects of propeller-shank design on inlet-pressure recovery were investigated. In connection with this study a method was developed whereby the flow fields of cowlings and cowlings-spinner combinations can be calculated from surface pressure distributions.

The Ames Laboratory has studied the effects of a propeller on the characteristics of submerged inlets for a typical gas-turbine-powered airplane. With the propeller providing no thrust, there was a loss of ram-pressure recovery that varied with the blade angle and angle of attack, but was relatively unaffected by variations of inlet-velocity ratio. As the thrust coefficient was increased, the ram-recovery ratio increased and eventually exceeded that obtained with the propeller removed.

Research on air inlets at high-subsonic and transonic speeds has been receiving greater emphasis because of the growing need for such data. The Langley Laboratory recently completed tests of a selected group of NACA 1-series nose inlets operating in the transonic speed range. It was the purpose of this project to show the degree to which critical Mach number can be estimated from low-speed pressure distribution.

In the supersonic range, theoretical and experimental investigations have been made of conical inlets having central bodies. Inlet configurations giving the best relation between pressure recovery and external drag were determined for the range of conditions investigated. Data obtained from this investigation have

made it possible to devise a method for the estimation of the drag and pressure recovery.

Because of the interest of designers in leading-edge air inlets on swept wings, the Ames Laboratory has investigated this type of inlet for a wide range of inlet velocity. Pressure-distribution, ram-pressure-recovery, and wake-survey data have been obtained. The ducted section of the wing was designed by the application of an analytical method developed for leading-edge inlets on unswept wings. It was found from these tests that thin duct lips were susceptible to laminar separation near the leading edge, resulting in high section drag.

The installation of electronic devices, armament, and other equipment in nose sections of aircraft limits the use of simple nose inlets. Thus, side inlets are of considerable interest. In some instances side-inlet installations permit attainment of low duct losses because of the short duct lengths used. In order to realize further gains in inlet-diffuser-duct efficiency, the Ames Laboratory has been working on a submerged inlet with a cascade of airfoils to diffuse and at the same time turn the air into the engine settling chamber. The results indicate that at least for large air deflections the cascade inlet has relatively good pressure recovery.

Boundary-layer control has been another means of increasing the performance of air inlets. Work at the Ames Laboratory on submerged side inlets with boundary-layer control has shown that an improvement in ram-pressure recovery can be realized, especially at low mass-flow ratios. It also appears that the stability characteristics of submerged twin inlets can be improved by the use of boundary-layer control. The quantity of boundary layer removed and thus the expenditure of power for this removal were found to be relatively small.

Other submerged-inlet configurations investigated were a parallel-walled inlet and an inlet with diverging ramp walls. These studies indicate that diverging the inlet ramp walls effectively extends the satisfactory operating limit of the submerged inlet to higher Mach numbers. The superiority of the divergent-walled inlet is attributed to the ramp boundary-layer characteristics associated with this configuration. The most promising of the submerged-inlet configurations are being studied at transonic speeds.

A study at large scale of submerged side inlets has continued in the 40- by 80-foot wind tunnel at the Ames Laboratory. The effects of sideslip on the efficiency of both single- and twin-inlet systems and the effects of mass-flow ratio on the stability of twin-inlet systems have been investigated. It was found that the recovery characteristics of either the single or twin inlet are relatively insensitive to small angles of sideslip. A well-

defined region of unstable flow and of reversed flow was encountered with the twin-inlet system at low mass-flow ratios. Studies to explain and clarify the cause of this flow instability and reversal have also been completed.

Continued research in the Ames 8- by 8-inch supersonic wind tunnel has shown that, at Mach numbers less than 1.8, extended side inlets can attain a total pressure recovery comparable with that of a nose inlet.

Ducts and Duct Elements

Air-handling components other than the air inlet have received detailed consideration. Two annular diffusers of different conical expansion angles but constant outer diameters have been investigated with rotating flow behind an axial fan at the Langley Laboratory. The performance characteristics of the diffusers were determined and the rotational-kinetic-energy effects on the over-all energy transformation were observed over a range of inlet Mach number and angle of flow. These results have been reported and show that a wide range of flow distribution is encountered as a result of changes in operating conditions. The over-all performance of an 8° diffuser was shown to be appreciably better than that of a 16° diffuser under comparable conditions. Sharp reductions in efficiency were recorded in both diffusers at the maximum values of stream rotation.

Further research on ducts in the 8- by 8-inch supersonic wind tunnel at the Ames Laboratory has shown that in supersonic flight, where the flow velocities in air inlets are relatively high, the design of the subsonic diffuser behind the inlet requires particular care. A duct shape that minimizes the adverse pressure gradient imposed upon the boundary layer produces a considerable improvement in pressure recovery.

A study of screens in wide-angle diffusers was made at the National Bureau of Standards under an NACA contract to determine the effect of screens on flow separation and flow turbulence. This study reported in Technical Note 1610 shows that screens can prevent separation and restore separated flow. The mechanism of the flow as affected by the screens is also discussed in the report.

Results of a study of friction coefficients in the inlet length of smooth round tubes conducted at the Massachusetts Institute of Technology under an NACA contract are reported in Technical Note 1785. The experimental results of this study are compared with theory. As a result of the study, an approximate method was developed for predicting the discharge coefficient of rounded-entrance flow nozzles.

Jet Exit Studies

Studies of exit influences on both the internal and external air-flow characteristics of aircraft are assuming greater importance with increasing flight speeds.

An investigation is being made at the Ames Laboratory of the effect of various asymmetrical exits on the direction of the jet reaction. The jet being studied issues from the end of a streamlined body. For the investigation jet-exit, cut-off angle was varied from 0° to 75°, the jet-exit velocity ratio (jet velocity to free-stream velocity) was varied from 0 to 1.0, and the maximum Mach number of the jet at the exit was 0.80. The investigation indicated that angularity of the pipe cut-off does not affect the direction of the jet reaction, but may have appreciable effects on the stability characteristics of an airplane if the mixing area of the jet influences the air flow about the controls or stabilizing surfaces.

Air ejectors for pumping cooling air for jet engines are coming into general use. Ejector studies have continued at the Lewis Laboratory with emphasis on theory of operation and performance. An investigation of the effect of operating temperature on ejector-pump performance and an analysis of ejector thrust by integration of surface pressures have been completed.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

During the past year, research efforts have been extended to improve the performance of propellers at high speeds. To this end, considerable effort has been expended in conducting high-speed, wind-tunnel investigations of propeller problems.

Blade Sections

An investigation was made to evaluate the effect of blade-section thickness ratio on the aerodynamic characteristics of a propeller. The investigation consisted of wind-tunnel studies of five related propellers having a wide range of section thickness ratio.

High-Speed Propellers

Preliminary studies have been made of the effects on propeller performance of the utilization of blades embodying sweep in the blade plan form. A propeller originally designed for flight research was investigated in a high-speed wind tunnel. The results provide a background of information on the operation of swept propellers at subcritical conditions.

It has been found that the introduction of sweep in a propeller blade introduces unusual and complex variations in the distribution of stress in the blade. As a result, special methods have been developed to determine and reduce the stresses and deflections in the blades of swept propellers.

An investigation has been made in which the static thrust characteristics of four related propellers differing in camber and blade width were determined. The results obtained are useful in providing basic information on the design compromises necessary to obtain

adequate performance for satisfactory take-off characteristics.

An investigation has been made in flight to provide basic information on optimum propeller-blade loadings for both the climb and high-speed conditions. The results obtained, which were reported in Technical Note 1784, indicate the large increase in power loadings which is required to obtain maximum efficiency at high speeds as well as the design compromises between the climb and high-speed conditions. In the climb condition, the increase in blade loading associated with a reduction in number of blades from three to two led to marked reductions in propeller efficiency, whereas for the high-speed, level-flight condition, even greater losses in propeller efficiency were associated with failure to obtain sufficiently high blade loadings to obtain maximum efficiency even with the reduced number of blades.

A contract investigation was conducted by Stanford University to determine the influence of blade-width distribution on propeller performance characteristics. Force and wake-survey data were obtained for a number of three-blade model propellers of equal activity factor and dissimilar blade plan forms. Although the differences in the efficiency envelopes for the various propellers were small, it was found that blades tapered from broad roots to narrow tips were more efficient than blades of relatively uniform width when operating at power coefficients greater than 0.1 and at advance ratios less than those for maximum efficiency. The results of the investigation are reported in Technical Note 1834.

Vibration and Flutter of Propellers

As a result of serious vibrational difficulties arising from the operation of large propellers in nonuniform flow fields and under conditions of pitch and yaw, a comprehensive program was initiated to determine methods of calculating the stresses involved as well as means of alleviating these stresses. Investigations on this problem are under way at both the Langley and Ames Laboratories. The applicability of existing propeller theory and the theory of oscillating airfoils to the problem has been studied.

SUBCOMMITTEE ON HELICOPTERS

In order to provide and interpret fundamental information on the factors which affect the flying qualities, performance, and reliability of helicopters, the NACA has enlarged and intensified its research in this field. In addition to theoretical studies, experimental investigations have been carried out on full-scale and small-scale models in flight, in wind tunnels, and on the Langley helicopter test tower.

Rotor-Blade Sections

Five NACA airfoil sections intended for use on helicopter rotor blades were designed and tested in the

Langley two-dimensional low-turbulence pressure tunnel. These airfoils have thicknesses varying from 9 to 15 percent of the chord and design lift coefficients from three-tenths to seven-tenths. Theoretical pressure distributions, together with measured values of the two-dimensional aerodynamic characteristics over a range of Reynolds number, were obtained for each airfoil. In addition, the effects of surface condition on the airfoil characteristics were determined. The results of the investigation, which are presented in Technical Note 1922, were analyzed to demonstrate the effects of variations in thickness and camber on the pertinent aerodynamic characteristics. Theoretical calculations for different flight conditions are included to indicate the relative performance of sample rotors employing the different airfoils. These calculations show that the new airfoils are inferior in performance, for most flight conditions, to the NACA 8-H-12 airfoil section developed in a previous investigation.

Rotor Performance

An investigation was made on the Langley helicopter test tower to determine the effects of wind velocity on rotor performance. This information was needed to enable correlation of data obtained under various wind conditions and on different rotors. The results of the investigation, reported in Technical Note 1698, were in essential agreement with simple momentum theory which indicates that rotor performance increases with increases in airspeed above zero. As an example, it was found that for a typical helicopter the power required to produce a given amount of thrust was 17 percent less in a 15-mile-per-hour wind than under zero wind conditions. It was also found that the effects of wind velocity on performance were virtually independent of blade load distribution.

An analysis of the steady autorotative vertical descent of a helicopter was made by Princeton University under NACA sponsorship. The effects of both constant and variable induced velocity over the rotor disk were determined and the results reported in Technical Note 1906. It was found that, although the assumption of constant induced velocity causes considerable error in the load distribution along the blade, the rotor speed and rate of descent for small angles of blade pitch are negligibly affected. For high angles of pitch where blade stalling is important the errors in theoretically computed blade load distributions may be expected to be sufficient to cause disagreement with experiment. A consideration of the forces of autorotation indicated that for small values of blade pitch these forces will be adequate for autorotation, and blade stalling can be neglected. At the higher values of blade pitch, however, the possibility of blade stalling resulting from an upward gust is increased.

An analytical study has been made by Princeton University of the motions of the helicopter in the transition range from hovering flight with power on to steady vertical autorotative descent following a power failure. The effects of hinging the blades, of blade moment of inertia, and of rate of pitch reduction after power failure were considered. The results of the study, which were reported in Technical Note 1907, indicate that the effect of blade flapping is negligible insofar as the establishment of steady autorotation is concerned. It was also found that in order to avoid excessive blade stalling during the transition, blade moment of inertia should be large and blade pitch should be reduced as rapidly as possible after power failure.

Stability and Control

As part of an investigation to establish satisfactory helicopter flying-qualities requirements and to determine means of satisfying these requirements, the flying-qualities problems of current helicopters as observed during flight were collected and are discussed in Technical Note 1799. This paper contains information on the flying qualities of helicopters obtained from performance testing, experience with various helicopter types, and knowledge of foreign work in this field. It was found that the principal problems of current helicopters are: Instability with angle of attack in forward flight; control sensitivity in forward flight, particularly for the smaller helicopters; and control forces following control movements during maneuvers. Some discussion is given of suggested remedies for these problems.

To aid in establishing criterions for acceptable helicopter stability characteristics, flight tests were conducted on a small single-rotor helicopter possessing stick-fixed longitudinal characteristics which were considered satisfactory by the test pilot. Time histories of longitudinal maneuvers were obtained for correlation with the test pilot's personal observations.

Vibration

The dynamic response of a helicopter rotor to oscillatory pitch and throttle movements was investigated on the Langley helicopter test tower to determine the natural frequencies of the drag-angle motion and the damping required to prevent excessive drag-angle oscillation response. Both symmetrical oscillations, in which all of the blades lag and advance together, and unsymmetrical oscillations, in which the blades are out of phase with each other, were studied. The results, which were reported in Technical Note 1888, showed that, whereas the frequency of the symmetrical drag-hinge oscillations was influenced by the engine and gearbox inertias and rotor-shaft torsional stiffness, the frequency of the unsymmetrical oscillations was affected

primarily by the rotor-pylon bending stiffness. These results were shown to be in agreement with predicted values and indicated that care should be exercised to insure the absence in the helicopter of regular disturbing forces, such as a hunting pitch and throttle governor or hunting automatic pilot, with frequencies near those of the resonant condition.

A contract investigation was carried out by the Polytechnic Institute of Brooklyn in which a theoretical study was made of the dynamic properties of helicopter rotor-blade systems. The study dealt with the application of the theory of small oscillations about a steady state of motion to a representative blade system hinged to a driving hub. The study covered the derivation of the angles of attack of the inflow, of the blade-position variables—pitch, flapping, and lagging—and of the aerodynamic inertia forces acting on hinged blades in both hovering and translational flight. Also included were the development and solution of the equilibrium conditions of the blade system and the development of the frequency, stability, and damping properties of hinged blades in both hovering and translational flight. Four combinations of relative constraint conditions between angles of pitch, flapping, and lagging were investigated. The results are reported in Technical Note 1430.

SUBCOMMITTEE ON SEAPLANES

Planing-Tail Hulls

Hydrodynamic research on the planing-tail type of hull has been continued in Langley tank No. 2 with forms representing the extreme in aerodynamic refinement for improvement of flight performance. These refinements indicate the extent of the hydrodynamic penalties to be paid for the compromises made to achieve low drag, but at the same time demonstrate the practicability of such forms for application to advanced seaplane designs. With the point of view adopted in the research toward over-all improvements in hull form, special techniques were necessarily developed in the tank for adequate evaluation of the hydrodynamic qualities of interest. Parallel investigations of refined planing-tail hulls were also conducted in the Langley 300-mph 7- by 10-foot tunnel to indicate the aerodynamic gains that might be achieved with this type of hull.

Length-Beam Ratio

An investigation of the effects of hull length-beam ratio on hydrodynamic characteristics in waves has been made in Langley tank No. 1, and the results are reported in Technical Note 1782. It is concluded that when the product of length squared times beam is held constant, as would very nearly be the case for interchangeable hulls on a given seaplane, the motions in trim and rise and the maximum probable vertical accelerations in

waves are substantially reduced as the length-beam ratio is increased. The maximum probable angular accelerations on the other hand are increased until extreme length-beam ratios are reached because of the increase in hull length associated with decrease in beam for a specific design.

The research to date is believed to establish broadly the upper limit from the standpoint of hydrodynamic characteristics beyond which no further over-all improvements may be expected from increase in hull fineness ratio alone.

Similar tank investigations of detailed modifications of the form of a hull having a high length-beam ratio are reported in Technical Notes 1828 and 1853. Forebody warp (progressive increase in dead rise from step to bow) and increase in afterbody length are shown to have marked favorable influences on behavior in rough water. Forebody warp greatly improved spray and overload capacity while increased afterbody length had a smaller adverse effect on these qualities. Other hydrodynamic characteristics of interest were relatively unaffected by the modifications.

The effects of combining the modifications are reported in Technical Note 1980. In general, the effects of the separate changes were additive to a certain degree resulting in a particularly promising hull form, with a high length-beam ratio, for open-sea operations. Inferior bow-spray characteristics associated with the lengthened afterbody alone were more than compen-

sated for by the improvements in this quality gained with the warped forebody.

The aerodynamic investigation of hull length-beam ratio in the Langley 300-mph 7- by 10-foot tunnel has been extended to very high ratios. The additional effects of the extreme ratios (of limited usefulness from a practical design point of view) on the aerodynamic characteristics were found to be small.

High-Speed Hydrodynamics

The long-range program of hydrodynamic research on methods of water-basing high-speed aircraft has been continued. The possibilities of various high-speed configurations and auxiliary devices for use in water operation have been evaluated and the fundamental characteristics of promising hydrodynamic lifting elements have been studied in Langley tank No. 2.

SPECIAL SUBCOMMITTEE ON THE UPPER ATMOSPHERE

The Special Subcommittee on the Upper Atmosphere has continued the collection of data for use in defining more accurately the physical characteristics of the upper atmosphere. Efforts are also continuing to improve instruments and techniques for measuring the physical properties of the atmosphere to altitudes of the order of 400,000 feet. When sufficient data are available from soundings by various rocket vehicles, it will be possible to modify and standardize the existing tentative upper-atmosphere tables published in Technical Note 1200.

PROPULSION RESEARCH

With the emphasis on higher speeds and on increased altitudes of operation, the objectives of propulsion research are to obtain a maximum of thrust for a minimum of engine frontal area, engine weight, fuel consumption, and manufacturing effort. Consideration must be given to each of these points and a suitable balance obtained. As pointed out in the previous annual report, the NACA research effort must provide scientific information applicable to at least five types of flight-propulsion engines—for high-speed flight, the turbojet, the ram-jet, and the rocket; and for lower flight speeds, the turbopropeller and the compound engine.

NACA efforts in this field have been assisted by the Committee on Power Plants for Aircraft and its seven subcommittees. Most of the research discussed in this section has been conducted at the Lewis Flight Propulsion Laboratory with additional assistance provided by the National Bureau of Standards and by educational and nonprofit institutions under contract to the NACA.

As a means of bringing the findings of the NACA to the aircraft and related industries with a minimum of

delay, conferences on specific phases of propulsion research have been held at the Lewis Laboratory in the past year. At these conferences significant NACA research results were presented on turbojet-engine thrust augmentation and on aircraft power-plant controls.

In achieving a greater thrust per unit frontal area the aerodynamic aspects of flight-propulsion research have assumed increased proportions and a need for further aerodynamic studies of propulsion problems is apparent. In order to obtain increased thrust per unit engine weight the research approach varies with the type of power plant, and for turbojet engines emphasis is being placed on components of greatly improved performance and decreased size, such as supersonic compressors. To obtain increased thrust per unit of fuel consumed an increase in the pressure ratio and operating temperature of gas-turbine-type engines is indicated. Effort is also being placed on possible simplification of the shapes of components of gas-turbine-type power plants in order to reduce the manufacturing effort required. The ram-jet and the rocket power plants are inherently suitable for high-speed flight as their

elements are already reduced to a minimum of frontal area and weight, and emphasis is placed on obtaining improved performance.

With a major share of research effort being devoted to the gas-turbine type of power plant, considerable research information on such power plants has been made available during the past year. Progress is being made in obtaining increased endurance life for gas-turbine parts at current operating temperatures. As progress continues it may be possible to alleviate the demand for scarce alloying elements for the heat-resisting parts of gas turbines. Once satisfactory endurance life is obtained it may be possible to commence utilizing materials which will be less expensive and easier to handle in manufacturing processes. With the application of turbine cooling it may be that marked improvement in aircraft gas-turbine performance may be obtained through the use of higher cycle temperatures and pressure ratios. Substantial progress has also been made in providing a fuel for use in aircraft gas turbines which will be relatively easy to manufacture because of the ready availability of its constituents and the absence of any knock-rating requirements.

The ram jet is the type of power plant that shows most promise of supplying at reasonable efficiencies the tremendous power necessary to drive aircraft in the atmosphere at extremely high speeds. The Lewis 8- by 6-foot supersonic wind tunnel that permits study of the aerodynamic and combustion characteristics of turbojet or ram-jet engines up to a Mach number of 2.0 has been placed in operation during the past year. The research program for this facility will supply greatly needed fundamental data on the design of power plants suitable for supersonic flight.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Engine Performance and Operation

An investigation of the altitude-performance characteristics of a centrifugal-compressor-type turbojet engine has been completed. The results indicated that under standard atmospheric conditions best thrust per pound of fuel is obtained at the tropopause. Attempts were made to predict performance by conventional generalization procedures and it was found that these procedures were not applicable to these engines above 20,000 feet because of a change in compressor performance with decreasing Reynolds number.

An investigation has been made of the altitude performance of two axial-flow turbojet engines. These investigations provided data on engine and component performance for altitudes up to 50,000 feet and flight Mach numbers up to and exceeding the speed of sound.

The data have been analyzed to show the performance of each of the major components of the engine. The combustion characteristics and blow-out limits were of particular interest.

A ram-jet engine was investigated at simulated altitudes to determine an efficient combination of flame holder and fuel. A series of flame holders was investigated using several different fuels. The results indicated the relative combustion efficiencies obtained with the different fuels, as well as the effects of flame-holder configuration on combustion temperatures, combustion efficiencies, and operable range of fuel-air ratio. Several flame holders and fuel-spray nozzles have been investigated in experimental captive flight tests using a rectangular ram jet which was integral with a subsonic wing section. Because the combustion process in a ram-jet engine may affect the efficiencies of the inlets and hence the net thrust obtainable, an investigation of the interaction between the combustion process and air inlet was made.

An experimental investigation was conducted to determine the improvement in the performance of a reciprocating engine resulting from compounding with an exhaust-gas blow-down turbine. A 12-cylinder, liquid-cooled, compound reciprocating engine was investigated over a range of engine and turbine operating conditions. The data obtained make it possible to predict the effect of independent engine and turbine variables on turbine power output. For comparison, the performances of five compound reciprocating-engine power plants have been calculated. These consisted of a 12-cylinder, liquid-cooled engine compounded with (1) a blow-down turbine, (2) a blow-down and steady-flow turbine in series, (3) all-gear supercharging, (4) turbosupercharging, and (5) a steady-flow turbine (Technical Note 1735).

Cooling characteristics of two different types of multicylinder, liquid-cooled, reciprocating engine were determined and the cylinder-head temperature and coolant heat rejections correlated with the primary engine and coolant variables. This correlation is similar to that previously developed from analysis of the cooling processes involved in a single-cylinder, liquid-cooled engine and permits the prediction of both the cylinder-head temperature and the coolant heat rejection for a wide range of operating conditions.

SUBCOMMITTEE ON AIRCRAFT FUELS

Availability of Fuels

Turbojet engines in the United States have been developed to operate with either kerosene or high-octane gasoline. Consideration by the military services and the NACA Subcommittee on Aircraft Fuels indicated that in case of a national emergency such fuels would not be available in sufficient quantity for an air force

with a large number of turbojet aircraft. A tentative specification was drafted that would include about one-half the refined products from a barrel of crude oil and this fuel was subsequently designated AN-F-58 by the military services. The Lewis Laboratory evaluated the performance of this new fuel in current-production turbojet engines.

A comparison of the performance of AN-F-58 fuel with the fuel currently specified for the particular engine was made in two altitude test chambers, in the altitude wind tunnel, and in flight, for a wide range of simulated altitude and flight Mach number. The engine investigated in one altitude test chamber was equipped with a centrifugal compressor and tubular combustors designed for a kerosene-type fuel. The engine investigated in the second altitude test chamber was equipped with an axial-flow compressor and an annular combustor designed for gasoline-type fuel. The altitude-wind-tunnel investigation was made on an engine equipped with an axial-flow compressor and tubular combustors designed for a kerosene-type fuel. The flight investigation was conducted with an engine incorporating an axial-flow compressor and tubular combustors designed for kerosene-type fuel. These full-scale engine investigations included a determination of engine thrust, specific fuel consumption, combustion efficiency, blow-out limits, ignition characteristics, and carbon deposition for both AN-F-58 and the current fuel specified for the particular engine. The results of the investigation showed that the use of AN-F-58 fuel resulted in performance equal in practically every respect to that with the standard fuel.

Effect of Fuel Characteristics on Turbojet-Engine Performance

The effect of fuel variables on the starting of turbojet combustors is under investigation. Some of the important parameters include the vapor pressure and the boiling point of the fuel, the fuel and air temperatures, the characteristics of the fuel spray, and the type of ignition source.

The effect of varying the boiling point, the aromatic hydrocarbon content, and the olefin content of fuels that fall within the AN-F-58 specification has been studied at simulated-altitude conditions in a number of turbojet combustors of different design. The performance parameters that were investigated include combustion efficiency, altitude operational limits, and carbon formation.

Early investigations indicated that fuels containing aromatic hydrocarbons deposited more carbon in combustors than paraffinic fuels. Studies on annular- and tubular-type combustors have indicated that carbon deposits may be correlated with hydrogen-carbon ratio

and volumetric average boiling point of the fuel. The relative quantities of carbon to be expected from fuels of different characteristics may be estimated by use of this correlation.

Fuel Synthesis

In some cases fuels required for evaluation in turbojet and ram-jet combustors are not available from commercial sources and in these cases the NACA prepares the fuels by isolation from petroleum stocks or from materials that will yield the desired product in a few steps. A large fractionating column has proved to be of considerable assistance in preparing drum quantities of these fuels.

Emphasis has been given to the synthesis of high-density hydrocarbons because the aircraft and missiles for high-speed use are volume limited. By studying the effect of systematically changing the molecular structure on the heating value and physical properties of hydrocarbons, there is a basis for predicting the type of molecular structure that will give optimum heat release per unit volume and optimum physical properties.

SUBCOMMITTEE ON COMBUSTION

Effect of Operating and Design Variables on Combustion

Long-range fundamental research on the physics and the chemistry of the combustion process has been continued. The research comprises attempts to analyze flames for the molecular species existing therein and studies of the effects of different catalytic agents on flame speeds. Both lines of attack are aimed at adding to the knowledge of the chemical mechanism of burning.

Following a completed study of the effects of air velocity, temperature, and pressure on the energy, power, and duration of a spark discharge for different electrode diameters and spacings, research was initiated on the energies required to ignite flowing combustible propane-air mixtures. These ignition studies have been completed for a pressure range of 1 to 2 pounds per square inch.

In the continuing effort to establish generalized rules and principles about the operation and the design of gas-turbine combustors, several combustors of different basic design were investigated over a wide range of altitude. The designs included both annular and tubular types, and also included combustors representative of both United States and foreign design.

With previously acquired knowledge of the influence of operating variables, or inlet conditions, on the performance of gas-turbine combustors, systematic research was conducted on specific design variables for

gas-turbine combustors. In one such study, the effect of fuel-nozzle size and fuel-injection pressure on the altitude performance of an annular combustor was determined. Inlet-air conditions were independently altered in the study. Results indicated that reduced fuel-nozzle size or increased injection pressure increased combustion efficiency at low heat-input values but produced lower temperature-rise limits. Variations in fuel volatility were made to verify the possible explanation for the observed phenomenon.

In another investigation, systematic research was conducted on the arrangements of the air passages in the walls of the combustor liner, or flame tube.

One method of augmenting the thrust of a turbojet engine is to lead some of the air from the compressor to a separate combustion chamber where it is burned with fuel. The air thus taken from the main combustors is replaced by a fluid, for example, water. A study was completed to establish the optimum location for injecting the water into a combustor and to determine the maximum quantities of water that can be injected without seriously depreciating the combustor performance.

Ram-jet combustion requires stable, efficient burning in a high-velocity air stream with a minimum of physical obstruction in the air stream. Because basic research showed the high efficiency of incandescent surfaces in supporting and stabilizing combustion, a performance comparison was made between a conventional single-row ram-jet burner and burners embodying one, two, three, and four rows of gutters immersed in the combustion zone.

Thermodynamic charts and computational methods previously established have been used to continue the evaluation of rocket-propellant systems that will give maximum thrust per weight flow and per volume flow. Experimental research on properties and characteristics of propellants has been conducted to establish the degree of suitability for any desired application. Propellants offering the possibility of greatly increased range of rocket-propelled aircraft as compared with alcohol and liquid-oxygen propellants have been experimentally evaluated in 100-pound-thrust engines.

Kinetics of Rocket-Motor Reaction

Design of the smallest, lightest, and most efficient rocket engine for a given thrust presupposes basic knowledge of the relation between propellant-injection characteristics and combustion. High-speed motion pictures of the combustion of liquid oxygen and gasoline in a rocket engine showed the effect of seven methods of propellant injection on the uniformity of combustion. The flame front was generally found to extend to the injector faces and all the injection systems showed

considerable nonuniformity of combustion. Pressure vibration records indicated combustion vibrations that correspond to resonant-chamber frequencies.

Heat-transfer research at high Reynolds numbers and high temperatures both with and without liquid films on the inside walls of a duct was initiated to provide basic information pertinent to rocket cooling.

SUBCOMMITTEE ON COMPRESSORS

Gas-turbine power plants for high-speed and long-range aircraft require light compact compressors with large air-flow capacities and high efficiencies. In addition, the compressors should be mechanically sturdy and easily manufactured in order to obtain reliable engines having a comparatively low initial cost. These goals are the objective of the research on two types of subsonic compressors—the axial-flow and the centrifugal or mixed-flow type—and on the supersonic compressor, each of which appears to have particular advantageous applications.

Theoretical Compressor Aerodynamics

Theoretical studies have been concentrated on determining the compressible potential flow associated with the configuration of the compressor and its operating conditions. Basic general equations governing the three-dimensional compressible flow in turbomachines have been developed in convenient forms to be used for both theoretical and experimental investigations. These equations were employed in determining the radial flow involved in, and its effect on, the design of two axial-flow compressors and a turbine with a large number of blades. The solutions obtained are for small, large, and infinite blade-row aspect ratios. As reported in Technical Note 1795, the radial motion is found to consist of a component due to the taper in the passage wall and an oscillatory component caused by the different radial variation of specific mass flow at different stations along the axis of the machine. The effect of the radial flow is increased with higher aspect ratio and flow Mach number.

With the assumption of the linearized pressure-volume relation, a solution of the problem of designing an airfoil with any theoretically attainable, prescribed, dimensionless velocity distribution in a potential flow of compressible fluid was obtained by a method of correspondence between potential flows of compressible and incompressible fluids (Technical Note 1913). The method was then extended to include the designing of cascade blades for a given turning of the air flow and a prescribed velocity distribution along the blade.

Besides the potential-flow studies, investigations have been made to determine the magnitude of some of the

limitations imposed on compressor performance by viscosity and compressibility. From consideration of available information on boundary-layer behavior, a relation of profile thickness, maximum surface velocity, Reynolds number, velocity diagram, and solidity has been established for a cascade of airfoils immersed in a two-dimensional incompressible fluid flow. The effect of various cascade-design parameters on minimum required cascade solidity has been developed by several illustrative examples (Technical Note 1941).

A theory developed for the analysis of two-dimensional compressible flow in centrifugal and mixed-flow impellers is presented in Technical Note 1744. The variables taken into account are: Tip speed, flow rate, number of blades, and passage-area variation. The analysis is first developed for arbitrary blade shapes and then applied to several specific shapes of blade.

An analytical study was made of four combinations of subsonic and supersonic flow in the rotor- and stator-blade passages of axial-flow compressors. A compressor with a rotor-contained normal shock and subsonic velocity at the stator entrance was theoretically capable of producing a total-pressure ratio of about 3.5 per stage. A compressor with a rotor-contained normal shock and supersonic velocities at the stator entrance permitted total-pressure ratios above 6.0 per stage. A compressor utilizing supersonic flow throughout the rotor with complete diffusion in supersonic stators permitted total-pressure ratios above 5.0 per stage. A compressor with subsonic velocity in the rotor and supersonic velocity in the stator entrance permitted pressure ratios of 2.2 per stage.

Experimental Compressor Aerodynamics

Investigations to determine methods of improving the performance of single-stage and multistage axial-flow compressors and of investigating the pertinent fundamentals of flow are continuing. In general, the research effort has been concentrated on increasing the pressure ratio per stage in order to reduce both the weight and the cost of axial-flow compressors.

An investigation was conducted on a 14-inch-diameter model of a typical inlet stage of a multistage axial-flow compressor to study the effect of the velocity diagram on pressure ratio, efficiency, and weight flow. The results of this investigation indicated that a compressor inlet stage designed on the basis of a symmetrical velocity diagram at all radii is capable of high flow capacities at reasonable stage pressure ratios and permits the use of the high rotor speeds that are desirable from the standpoint of high pressure ratio in the latter stages of a multistage compressor.

Several investigations have been conducted to determine the performance of large centrifugal compressors

that are components of aircraft gas-turbine power plants. A series of four compressor configurations was experimentally investigated to determine possible sources of losses and to analyze improvements afforded by subsequent modifications. Design changes in the impeller and the diffuser resulted in a 36-percent increase in weight flow (without any over-all change in power-plant size), a 5-point increase in over-all efficiency, and an increase in peak pressure ratio of 11 percent at the operating speed of the power plant.

The effects on compressor performance resulting from injecting water (or other fluids) into the impeller for augmentation purposes have been analyzed. For the inlet conditions considered and for pressure ratios below 8:1 this study showed that water-air ratios less than 0.05 were very effective in increasing pressure ratio and weight flow. When the water rate is increased above this figure, however, the excess water is essentially wasted, as far as compressor performance is concerned. The method of analysis was then applied to the data obtained from three large double-entry centrifugal compressors operated with water injection at the impeller inlet at a water-air ratio of 0.05. Although the pressure ratio and weight flow of the compressor were increased, the power required to drive the compressor increased to such an extent that the adiabatic efficiency was reduced by over 10 percentage points. This impairment in efficiency does not nullify the gains in engine performance resulting from the observed increases in pressure ratio and weight flow.

An analysis of a compressor utilizing supersonic flow throughout the rotor and experimental investigations on two-dimensional turning passages to simulate the blade shapes of such a compressor have been completed. The measured losses on the two-dimensional turning passages varied from 5 to 15 percent of the inlet stagnation pressure, the smallest loss being obtained for a passage in which separation on the convex surface was minimized through introduction of a favorable pressure gradient.

Vibration Analyses of Compressors

An investigation was conducted to determine the factors affecting the vibration of axial-flow compressor blades. Inlet disturbances at the entrance guide vanes were found to affect the vibrations of all stages of a 10-stage compressor. In general, the tendency was to increase blade vibration, but in some cases the arrangement of the disturbances had the beneficial effect of reducing vibrations. Of the various factors tending to damp blade vibrations, aerodynamic damping was found to be the most important. Approximately four-fifths of the total damping in the experimental compressor was attributable to aerodynamic effects.

The effects of centrifugal force on the flutter of compressor and turbine blades were investigated. Two methods of analysis were used in the investigation. The first was an approximate method, employing the conventional assumption that the flutter motion could be represented by just two degrees of freedom, the fundamental uncoupled torsion, and bending modes. In the second method, a solution of exact equations of flutter motion in a field of centrifugal force was obtained. Both methods showed essentially the same results: Centrifugal force can be detrimental by reducing the critical flutter speed, but if the flutter coefficient is kept below approximately 4, which is generally the case for compressor and turbine blades, there is little possibility of the occurrence of flutter at low angles of attack. Hence, the important cases of observed compressor and turbine-blade flutter are of the "stalling-flutter" type.

Under NACA sponsorship the Massachusetts Institute of Technology has designed and investigated a condenser-type microphone to take instantaneous pressure measurements under conditions typical of those existing behind the rotating blade elements of a compressor or turbine. The principal design element of this instrument is a dome-shaped diaphragm which is fitted to a standard pressure indicator and recording system. The dome-shaped diaphragm was shown to have a better frequency-sensitivity characteristic than a flat-plate-type diaphragm. Also, with regard to the problem of instantaneous pressure measurements, the response of a pitot-tube system to large-amplitude pressure fluctuations has been studied. A sound generator was designed to produce the large-amplitude fluctuating pressure and various pitot-tube systems were investigated.

SUBCOMMITTEE ON TURBINES

Experimental and theoretical research investigations on turbines having the general objectives of improving the efficiency, flow capacity, and expansion ratios across the turbine are continuing. Blade shapes that satisfy the aerodynamic, thermodynamic, and strength requirements, and which are easy to manufacture, are essential to the development of the turbines for gas-turbine power plants of high-speed, long-range aircraft. Research on methods of cooling turbine blades is also receiving emphasis because turbine cooling offers a means of utilizing low-alloy materials, as well as permitting operation at higher turbine-inlet temperatures.

Theoretical Turbine Aerodynamics

The similarity of the aerodynamic problems arising in compressor and turbine research makes the results of

nearly all the theoretical research on compressors applicable to turbines. Also, owing to the fact that the solidity of turbine blades is usually much greater than that of compressor blades, the comparatively simple "stream-filament" methods can be used to correlate theoretically the turbine-blade shapes with the velocity distributions in compressible flow. By using the basic principles of the stream-filament method, a step-by-step procedure has been devised for designing turbine blades with given velocity distributions on the suction surfaces (Technical Note 1931).

The difficulties in instrumenting rotating turbine blades to obtain fundamental information about the complex-flow phenomena have resulted in research with both two-dimensional and annular static cascades. A comparison was made between the calculated design performance of a gas-turbine stator blade and its performance in a sector of an annular cascade tunnel. Information was obtained on the three-dimensional effects that occur and the influence these effects have upon various performance parameters. The gas velocities on the blade surfaces were computed by the stream-filament method and then compared with the experimental values (Technical Note 1810).

The analytical determination of the performance of a gas-turbine engine under various operating conditions or the prediction of engine performance at other than design conditions requires a knowledge of the complete performance of each of the engine components. A method was developed for estimating turbine performance from the blade angles and flow areas. The method is based on assumptions that determine the variation of turbine-blade pressure losses and turning angles with variations of angle of incidence and entrance Mach number. The performance of a turbine of an aircraft gas-turbine engine was determined by means of the analytical method and the results compared favorably with experimental data.

A method of obtaining turbine-performance characteristics by use of a combination of two-dimensional and three-dimensional stationary-cascade investigations has been developed. The object of this study was to reduce the experimental work required to predict turbine performance.

Experimental Turbine Aerodynamics

A family of turbine rotor-blade designs based on one-dimensional flow theory and incorporating systematic changes in design variables is being investigated. A single-stage turbine having 40-percent reaction had a maximum internal efficiency of 84 percent at a total-pressure ratio of 3.5 and a hub-tip ratio of 0.8.

The air flow in turbines generally encounters favorable pressure gradients and therefore the problem of

attaining high blade-element efficiencies with turbine blades is not nearly so acute as in the case of compressor blades. The losses arising from blade-tip leakage and from improper flow distribution ahead of the turbine rotor, however, may seriously impair turbine performance. In order to determine some effects of stator-cone angle and blade-tip leakage, a single-stage turbine was investigated with stator-cone angles of 70° and 0° and with two stationary shrouds: (1) A labyrinth, no-leakage shroud and (2) a cylindrical, stationary shroud. In combination with the labyrinth shroud the 0° cone-angle stator gave a turbine efficiency slightly higher than the 70° cone-angle stator. When the labyrinth shroud was replaced by the cylindrical shroud, the effect on efficiency was negligible.

Theoretical Turbine Thermodynamics

Analyses have been made to explore the efficiency of various methods of blade cooling. Analytical investigation of the use of ceramic coatings as insulation on water-cooled turbine blades indicated that, in order to obtain practical results, a very low-conductivity coating must be used. With such coatings, many metals and alloys with intermediate conductivities (between 15 and 210 Btu/(hr) (sq ft) ($^\circ\text{F}/\text{ft}$)) might be suitable for turbine use.

Preliminary studies of the use of low-alloy materials for cooled turbine blades for application to a turbojet engine were made. It was found that the current values of turbine-inlet temperatures could be obtained with air-cooled blades made from low-alloy materials by having fins inside the blades to give large heat-transfer surfaces. Slight increases in specific fuel consumption are necessary, however, for maintaining the thrust of the engine when use is made of cooled turbine blades.

Experimental Turbine Thermodynamics

Experimental data on the heat transfer from hot gas to a cooled cascade of impulse blades and from cool gas to the same cascade of blades in a heated state have been obtained. To date, the use of a velocity and a pressure that are the averages of the velocities and the pressures about the blade as the basis for Reynolds number determination has provided the best correlation of these data. It was found that the heat-transfer coefficients for impulse blades are higher than those for reaction blades and that the blade angle of attack has a large effect on the heat-transfer coefficients.

An investigation was conducted to determine the effect of turbine-disk cooling with air on the efficiency and the power output of a radial-flow turbine. Over the normal operating range of the turbine, varying the corrected cooling-air weight flow from approximately 0.30 to 0.75 pound per second produced no measurable

effect on the shaft horsepower or adiabatic efficiency. Varying the turbine-inlet total temperature from $1,200^\circ$ to $2,000^\circ$ R. caused no measurable change in the corrected cooling-air weight flow.

Stress and Vibration Analyses of Turbines

In the preliminary stage of engine design or in a comparative evaluation of various types of power plant, it is desirable to have a method of obtaining the approximate weights of the various engine components and of determining the relative influence of various design variables. An analysis was made to show the effects of blading aspect ratio and solidity, the ratio of centrifugal stress at the blade roots to that in the disk, and the ratio of wheel diameter at the blade root to wheel diameter at the blade tip on turbine-wheel weight for a wheel model based on the DeLaval equation for a disk of uniform strength (Technical Note 1814).

Considerable attention was directed to stress and vibration problems of hollow blades for gas turbines. Hollow blades are subject to more serious vibrations than those encountered in solid blades. In an investigation of two blades of similar aerodynamic design, one solid and one hollow, it was found that approximately twice as many vibration modes were readily excited in the hollow blade as in the solid blade. Peculiar to the hollow blade was a very easily excited "breathing mode" in which the two sides of the blade moved alternately toward and then away from each other, causing stress concentrations to be produced at the leading and trailing edges of the blade.

A direct rational method has been developed for designing turbine disks to operate at any desired stress distribution resulting from the centrifugal effects of rotation and thermal effects of conduction from the hot gas. By this method, it is possible to design disks each portion of which operates at a uniform level of stress-to-strength ratio, thus resulting in engines of minimum weight and most efficient utilization of scarce alloying materials (Technical Note 1957).

An experimental investigation was conducted to check a theory explaining the occurrence of rim cracking of gas-turbine wheels with welded blades. The theory asserts that cracking is the result of subjecting the rim material to plastic flow alternately in compression as a result of high-temperature gradient and in tension as a result of residual stresses upon cooling. In the experimental investigation, a disk that had previously been used in an engine and several small simulated turbine disks containing machined stress concentrations were subjected to thermal cycling similar to that undergone by disks in service operation. The occurrence of rim cracking in accordance with theoretical predictions, particularly their occurrence during the

predicted cooling portion of the cycle, verified the theory and pointed to several remedial measures that could be taken to minimize or prevent such rim cracking.

SUBCOMMITTEE ON HEAT-RESISTING MATERIALS

Fundamental Factors Affecting the Strength of Materials

Certain gas-turbine parts must withstand thermal shock caused by rapid cooling and heating. An analysis was made to determine which properties of ceramic materials affect their resistance to fracture by thermal shock. A criterion was developed from this analysis and was qualitatively verified by experiment. Resistance to fracture by thermal shock was shown to be dependent upon thermal conductivity, tensile strength, thermal expansion, and ductility modulus (ratio of stress to strain at fracture) (Technical Note 1918).

Phenomena such as age hardening, annealing, and order-disorder transformation depend on the ability of atoms to migrate through an atomic lattice. One method of determining the movements of atoms within a lattice is to study the rates at which metals diffuse into each other under controlled conditions. A special case of diffusion in metals is the case of self-diffusion. In a theoretical study an expression for the diffusion constant for self-diffusion in metals was derived based on the assumption that self-diffusion occurs by the vacancy mechanism (Technical Note 1856).

Simple bonding experiments were made to indicate the compatibility of various metals and of ceramics to form a ceramal (a mixture of high-melting-point metal and refractory oxides or carbides). The temperature, time at temperature, and atmosphere suitable for sintering the ceramal were indicated by the results of these preliminary experiments. The bonding experiments conducted with boron carbide and each of four metals showed that cobalt, iron, and nickel formed a bonding zone between the metal and the ceramic and that chromium showed physical wetting characteristics on the ceramic (Technical Note 1948).

The NACA sponsored an investigation at the University of Michigan on the fundamental effects of aging and solution-treating on the creep properties of low-carbon N-155 alloy. In this investigation the reactions taking place during aging were partially defined and measured. A theory was outlined describing the role of precipitation and its effect on creep properties.

Another phase of the University of Michigan investigation concerned the effects of heat treatment and hot-cold work on properties of low-carbon N-155 alloy. It is expected that the trends shown in this investigation

for the various treatments will hold for other alloys. It is not expected, however, that the optimum treatments will be the same for all alloys. It was concluded that wide ranges in properties of most of the better alloys developed for gas-turbine service have been due to the influence of heat treatment and processing conditions. The treatments used have been of more influence than wide ranges in chemical composition. The properties of alloys in the hot-worked condition are quite variable because hot-working simultaneously involves solution treatments, aging, and hot-cold work.

As a means of extending basic knowledge on heat-resisting materials the NACA has sponsored an investigation at the University of Notre Dame on the chromium-cobalt-nickel alloy system. A preliminary survey of this system has been completed at 1,200° C.

Evaluation of Material Properties

Short-time tensile strength, thermal-shock resistance, coefficient of linear expansion, and density of seven hot-pressed ceramics were determined. The compositions of the ceramics were magnesium oxide, titanium carbide, zirconium carbide, boron carbide, 85 percent silicon carbide plus 15 percent boron carbide, silicon, and zirconia stabilized with 6 percent lime. Titanium carbide had the best resistance to thermal shock and showed the best over-all characteristics of the seven compositions investigated.

The properties of ceramals of titanium carbide plus 5, 10, 20, and 30 percent of cobalt, molybdenum, and tungsten were investigated. The properties evaluated were elevated-temperature tensile strength, elevated-temperature modulus of rupture, coefficient of linear expansion, and density. A study was also made of the microstructure of the ceramals. The ceramals exhibiting the highest strength as determined by modulus-of-rupture evaluations at 1,600° and 2,000° F. were 80 percent titanium carbide plus 20 percent cobalt and at 2,400° F. were 90 percent titanium carbide plus 10 percent molybdenum. It was thus shown that the use of metals having better refractory properties imparted higher strengths at the higher temperatures (Technical Note 1915). Further studies of these titanium-carbide-base ceramals were made to determine their oxidation-penetration characteristics at various temperatures and exposure periods. The ceramals containing molybdenum showed the least resistance to oxide penetration and the tungsten and cobalt ceramals were about equal in the time-temperature range for which the data were comparable. The oxides formed on the molybdenum ceramals had no protective value in inhibiting further oxidation, whereas the oxides formed on the tungsten and cobalt ceramals served as protective coatings (Technical Note 1914).

An investigation sponsored by the NACA at the University of Michigan produced data on stress rupture and creep properties of S-590 alloy, S-816 alloy and Inconel-X alloy from large forged disks similar to those used for gas-turbine wheels.

The investigation at the University of Michigan also showed that the 100- and 1,000-hour rupture strength at 1,200° and 1,300° F. varied approximately linearly with the cobalt content of alloys with 20 percent chromium, 20 percent nickel, 4 percent molybdenum, 4 percent tungsten, 4 percent columbium, and the remainder iron. Cobalt apparently stabilizes and controls the type and distribution of precipitated particles which give these alloys their high-temperature strength.

An investigation was also undertaken at the University of Michigan to determine by means of tensile tests whether service in combustion chambers of jet engines, estimated to be at 1,700° to 1,800° F., would increase the brittleness at 1,200° to 1,400° F. The results showed that the operation at the higher temperatures would not adversely affect the ductility at 1,200° to 1,400° F. as measured in the tensile test. In fact, ductility seemed to be improved by exposure at the higher temperatures.

Performance of Materials under Operating Conditions

An investigation of turbojet combustion-chamber liners from two types of engines was conducted to determine the factors contributing to liner failure by cracking. It was found that buckling was produced at or near most cracks by thermal stresses that resulted from over-all temperature gradients and from local temperature gradients at louvers in the liners. Cracks that formed in the buckle were attributable to thermal fatigue. The results indicated that cracking may be retarded and liner life prolonged by removing stress-raisers produced by punching operations (Technical Note 1938).

Ceramals offer promise of permitting higher operating temperatures in gas-turbine engines. The problems arising in the use of a carbide-type ceramal for gas-turbine blades were evaluated. Specimens of a ceramal composed (by weight) of 80 percent titanium carbide plus 20 percent cobalt were investigated. Gas-turbine blades of this material were operated in a quasi-service evaluation unit. The results indicated that this carbide-type ceramal may be suitable for gas-turbine-blade operation at relatively high temperatures for short times (Technical Note 1836).

The effectiveness of chrome plating in preventing oxidation and erosion of graphite rocket nozzles was investigated. This investigation was conducted on a 1,000-pound-thrust acid-aniline rocket. The results showed

that a thin chromium plating on the internal surface of graphite nozzles was effective in preventing the oxidation and the erosion that occurred during a run with unprotected graphite.

As a part of the research program on protective coatings for high-temperature materials an investigation was conducted on two ceramic coatings developed by the National Bureau of Standards to determine their suitability for turbine-blade application. Operation of blades with these coatings in a turbojet engine indicated that the fusion temperature of one was too low and some of the coating was thrown off. The other coating remained intact through 83 hours of operation except for a small amount of flaking caused by mechanical damage to the blades.

SUBCOMMITTEE ON PROPULSION-SYSTEMS ANALYSIS

Comparative Performance of Various Engine Cycles

A method for predicting equilibrium performance of turbojet engines was developed, with the assumption of simple model processes for the components. Results of the analysis were presented in terms of dimensionless parameters derived from critical engine dimensions and over-all operating variables. The analysis was made for an engine in which the ratio of axial-inlet-air velocity to compressor-tip velocity is constant and approximates that of turbojet engines with axial-flow compressors (Technical Note 1956).

The characteristics of a turbine and a propeller were investigated to determine the conditions of maximum-efficiency operation when utilized as an independent turbine-propeller combination. A method was developed for matching turbine and propeller characteristics for maximum over-all efficiency. The conditions for maximum-efficiency operation were found to be defined adequately by turbine-inlet temperature, pressure ratio, and propeller speed for all flight conditions investigated (Technical Note 1951).

Theoretical and experimental investigations were conducted to determine the performance potentialities of a highly compounded engine of the gas-generator type consisting of a two-stroke-cycle compression-ignition engine driving a compressor with a turbine driven by the exhaust from the engine. The turbine furnished the useful work of the cycle. Analyses of this type of power plant have indicated a very low specific fuel consumption combined with low specific weight and frontal area. The gas-generator-type engine has been evaluated analytically by comparing the pay-load-range performance of an airplane equipped with this type of power plant with the same airplane equipped with several other contemporary engines. Experimental investi-

gations have been undertaken to check the assumptions pertaining to the performance of the reciprocating-engine component of the gas-generator-engine analysis.

The very high manifold pressures associated with the gas-generator-type of engine require the use of a high-pressure-ratio compressor system. An analysis of the various compressor combinations indicates that compressor systems can be provided that should give satisfactory operation and control for altitudes from sea level to 50,000 feet.

Thrust Augmentation

The performance of different types of "clamshell" variable-area exhaust nozzles for turbojet engines has been determined on afterburners and standard tail pipes, using full-scale turbojet engines at zero-ram sea-level conditions. This type of nozzle properly designed is mechanically reliable under after-burning conditions. Efficiencies of the various types were within 0 to 8 percent of the efficiency of conventional fixed-area exhaust nozzles.

The operational and performance characteristics of two different types of commercial afterburner and several NACA afterburner designs augmenting the thrust of commercial-type turbojet engines have been determined in altitude test facilities. Determinations were made of the operable range of afterburner fuel flow, burner-ignition characteristics, stability of combustion, and burner-shell temperatures, over a range of simulated-flight conditions for each configuration. Marked improvements in the operation and the performance of tail-pipe burners were obtained by means of systematic modifications of the flame holder and fuel system. Results obtained with these modifications extended the knowledge of design requirements for tail-pipe burners.

Thermodynamics and Heat Transfer

Based on an analysis of the compressible-flow variations occurring in heat-exchanger passages, working charts have been constructed to enable convenient determination of the pressure drop sustained by air flowing in turbulent motion through a smooth-wall passage heated to constant-wall-temperature conditions. The effect on the flow process of a high temperature differential between the passage wall and the fluid may be accounted for in the use of the charts by a method derived from recent NACA experimental data.

The experimental investigation to obtain surface-to-fluid heat transfer and associated pressure-drop information at high surface temperatures and flux densities has been extended to average surface temperatures of 2,050° R. and heat flux densities of 15,000 Btu per hour per square foot. An additional investigation was conducted with air flowing through an electrically heated

silicon-carbide tube at average surface temperatures up to 2,500° R.

Control Problems

The problem of accurate fuel metering for reciprocating aircraft engines has become of increasing importance in recent years because of the development of long-range, high-altitude aircraft. An analysis of aircraft-carburetor design was completed which dealt primarily with altitude-compensating systems. A practical method was derived, which presents a possible means of obtaining accurate altitude compensation (Technical Note 1874).

The current development of gas-turbine engines indicates a future trend toward a wide variety of engine types. As new engines are developed by combining basic components of existing engines, the control problem presented by each engine type will be different. A general algebraic method of attack on the problem of controlling gas-turbine engines having any number of independent variables was developed employing operational functions to describe the assumed linear characteristics for the engine, the control, and other units of the system (Technical Note 1908).

A basic problem confronting the designer of engine controls is that of determining the dynamic behavior of the complete engine and control system under varying conditions of operation. A method of analysis was developed to obtain the frequency response characteristics of a complete system assuming the system to be linear and provided appropriate transient data were available (Technical Note 1935).

SUBCOMMITTEE ON LUBRICATION AND WEAR

Needle Bearings

An analytical and experimental investigation was made of needle bearings at rotating speeds to 17,000 rpm. The analytical factors considered included: Stresses due to aircraft maneuvering loads, deformations due to operation at high temperatures, and internal forces within the bearing. An expression for end thrust was derived wherein end thrust was found to be approximately equal to the external load multiplied by an over-all equivalent coefficient of friction. This equivalent coefficient of friction was experimentally obtained over a wide range of operating conditions. It was found that the stiffness of the needle was a significant factor with shaft deflection present. The experimental results for end thrust developed within a needle bearing agreed qualitatively with the derived expression. In general, the percentage of slip within the bearings increased with increase in speed. The data

indicated that the orbital needle speed may become independent of shaft speed at high values of shaft speed and at low loads (Technical Note 1920).

Bearing Erosion

The erosion of bearings is a constant source of trouble in many bearing applications. An investigation was conducted to determine the effect of high shear rates on erosion of common bearing metals. Studies were made with filtered oil flowing at mean surface shear stresses of 11 and 43 pounds per square inch (roughly corresponding to mean surface rates of shear of 1.0×10^6 and 19×10^6 reciprocal seconds, respectively) for periods of 6 hours. Under these conditions, specimens of copper, silver, and lead showed no indication of erosion or other surface damage. Studies made by flowing unfiltered oil through a flow path, one surface of which constituted the erosion specimen, produced a pseudoerosion that resembled erosion found in aircraft power plants. This pseudoerosion was found, by visual observation, to be caused by small foreign particles creating a multiplicity of small scores on the specimen surface. It was further observed that particles smaller than the oil-film thickness were capable of producing another type of erosion if the oil in which the particles were carried was forced to change direction suddenly (Technical Note 1887).

Sliding and Rolling Friction

An experimental investigation was conducted to establish the oxidation characteristics of molybdenum disulfide (MoS_2) and to determine the effect of such

oxidation on its role as a solid-film lubricant for relatively high temperature conditions. The oxidation characteristics were established with elevated-temperature X-ray-diffraction techniques. The effects of various degrees of oxidation of surfaces coated with MoS_2 on friction at high sliding velocities were studied. With sliding velocities between 50 and 8,000 feet per minute and a load of 269 grams, a coating of MoS_2 serving as a solid-film lubricant maintained low friction values during its oxidation as long as an effective sub-film of MoS_2 remained. Films of the oxidation product of MoS_2 (namely, molybdenum trioxide) alone produced very high friction. When heated in air at 750°F ., MoS_2 began to oxidize at a very low rate, the rate increasing steadily and becoming high at $1,050^\circ \text{F}$. and above. When heated to $1,000^\circ \text{F}$. in vacuum, MoS_2 maintained its original hexagonal structure (Technical Note 1882).

Oil Foaming

Under certain types of operation in aircraft the foaming of lubricating oil can prevent adequate lubrication of critical engine components. An investigation of the fundamental factors affecting the foaming characteristics of lubricating oils was conducted at Stanford University under the sponsorship of the NACA. The results of this investigation are reported in Technical Notes 1840, 1841, 1842, 1843, 1844, 1845, 1846, and 1847. Data were obtained on a number of commercially available products showing their tendency to foam relative to each other. In addition, theories were proposed for the behavior of the various materials studied.

AIRFRAME CONSTRUCTION RESEARCH

COMMITTEE ON AIRCRAFT CONSTRUCTION

The Committee on Aircraft Construction has during the past year reviewed the programs of research under its cognizance with particular emphasis on the problem of predicting the fatigue life of aircraft. The importance of take-off, landing, and taxiing problems as influenced by the increasing speed and size of aircraft has also received attention. As in the past, a considerable amount of the NACA research effort on structural materials and structures was performed under contract by universities and other nonprofit scientific institutions.

Fatigue Life of Aircraft

Research pertaining to airframe construction involves both the determination of the operating conditions of the airframe as well as the investigation of suitable materials and structures to meet these conditions. Investigation of the factors affecting structural design introduces problems of joint concern to the structures

engineer and the aircraft-loads engineer. One of these problems is the prediction of the life of aircraft as affected by fatigue.

During the past few years the trend in aircraft design and operating procedures has been such as to cause the problem of fatigue of aircraft structures to become of serious concern. In line with this trend the Committee on Aircraft Construction during the past year has reviewed both the fatigue problem and the program that has been under way to alleviate it.

The problem of predicting quantitatively the fatigue life of aircraft structures under service operating conditions may be considered to consist of two phases: (a) The determination of the repeated service loads and (b) the determination of the resistance of the structure to the repeated loads. These two phases of the problem are interrelated: The resistance of the structure to repeated loads depends on the manner in which the loads are applied; yet adequate measurement and expression

of these loads require a knowledge of how the resistance of the structure depends on the manner of loading. This interrelation requires that the fatigue problem be regarded as having a third phase (c), the development of a reliable theory relating fatigue life to manner of loading.

Phase (a) of this problem consists of the determination of repeated service loads as functions of the important operating and structural parameters, and the adequate expression of these loads. During the past year, emphasis has been placed on gust loads, as these appear to be of the greatest importance. The results of gust-loads studies are outlined in the section entitled "Subcommittee on Aircraft Loads."

Phase (b) of this problem consists of the determination of fatigue properties of basic materials, the effects on these properties of stress-raisers resulting from fabrication, the fatigue properties of structures, and finally the effects on these properties of the manner in which loads are applied. The first two parts of this phase are discussed in the section entitled "Subcommittee on Aircraft Structural Materials." The latter two parts are considered to be in the sphere of interest of the Subcommittee on Aircraft Structures and investigations directed toward the solution of these problems are currently under way.

Phase (c) of this problem, which concerns the evaluation of the fatigue damage caused by the cumulative effect of various loads, appears possible only after a large amount of fatigue data has been obtained under very carefully controlled conditions. Having such data, it should be possible to appraise existing damage theories and, if necessary, to develop a new theory. It is intended that the investigations now under way should provide satisfactory data for establishment of a reliable damage theory.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Stress Distribution

The buckling resistance of a plate to one type of load is usually lowered by the presence of another kind of load. The most important of the load combinations is that consisting of shear, which arises in the wing skin from twisting, and compression, which arises from bending. The buckling strength of flat plates under the simultaneous action of these two loads was studied experimentally through tests on long square tubes (Technical Note 1750). The results were found to validate the use of the theoretical parabolic interaction curve which applies to an isolated plate.

In conjunction with the foregoing investigation, a theoretical study was made of the buckling behavior of

a seamless square tube under torsion and compression in order to evaluate the extent to which the buckling strength of a square tube differs from that of four isolated plates (Technical Note 1751). The major difference found was that for a square tube more than 35 percent of the critical shear stress can be applied before the compressive strength is in any way reduced, whereas for an isolated plate the presence of some shear always reduces the amount of compressive stress required for buckling.

In most studies of the compressive buckling of flat plates, the prebuckling stress was assumed to be uniform throughout the plate. There are many practical cases, however, in which the compressive stress is not uniform but varies from one loaded edge to the other, as, for example, when the plate forms part of the upper skin of an airplane wing in bending. The buckling of a simply supported plate under a linearly varying compressive stress was therefore studied theoretically (Technical Note 1891). The results showed that a plate with a linear stress gradient will buckle with an average stress that is lower, but with a maximum stress that may be appreciably higher, than the uniform compressive buckling stress of the same plate.

Stability

At a conference on aircraft structures held at the Langley Laboratory in May 1948, it was mentioned that the use of vertical posts to replace interior shear webs was being considered seriously by the aircraft industry. As a first step in the study of this type of construction, the compressive buckling of simply supported flat plates supported in the interior by equally spaced rows of rigid posts was investigated. It was found that such plates buckle with either transverse nodes or longitudinal nodes passing through the rigid posts, the occurrence of one buckling mode or the other depending upon the number and spacing of the posts.

For the achievement of high strength to resist the compressive forces arising from wing bending, the upper surface of the wing is usually reinforced by longitudinal stiffeners. Charts giving the compressive buckling strength of simply supported flat plates so reinforced have therefore been computed (Technical Note 1825). Plates with one, two, three, or an infinite number of identical, equally spaced stiffeners having zero torsional stiffness were considered.

The compression skin of the wing is sometimes stabilized by chordwise rather than spanwise stiffeners. The results of a compressive-buckling analysis have been used to construct charts for the minimum-weight design of this type of construction (Technical Note 1710).

The design of wing spars having shear webs with uprights and the design of chordwise-stiffened, wing-

skin panels to resist wing torsion require a knowledge of the buckling strength of transversely stiffened long plates under shear. This problem was studied theoretically for simply supported flat plates in which the stiffeners are identical, are equally spaced, and have zero torsional stiffness (Technical Note 1851). Experimental results were found to be in good agreement with theoretical results.

The longitudinally stiffened panel of small aspect ratio has long been one of the most important structural components for which large amounts of experimental data have been accumulated. In order to make these data useful in design, a system of direct-reading charts had been developed to make possible the determination of the stress and panel properties required for a given loading; the first set was published last year. Two additional sets have been published as Technical Notes 1777 and 1778 for panels of 24S-T alloy with Y-stiffeners and Z-stiffeners, respectively.

The Y-stiffener (with straight webs) had been developed in order to achieve higher efficiency than that which could be obtained by conventional stiffener shapes. As a further improvement Y-stiffeners with curved webs were developed. Tests in a series of panels with such stiffeners of 75S-T aluminum alloy showed increased efficiency in panels designed to fail at high stresses (Technical Note 1787).

Previous work on panels with formed stiffeners had indicated that the Z-stiffener, which is very desirable from the production point of view, has also a high structural efficiency. In order to give thorough coverage on this type of stiffener, a program on panels with extruded (instead of formed) Z-stiffeners was undertaken. The data obtained to date on 75S-T aluminum-alloy panels have been published in Technical Note 1829.

The investigation of the effect of rivet diameter and pitch on the strength of compression panels has been continued. In Technical Note 1737, a marked effect of rivet strength on the local buckling strength of Z-stiffeners was reported.

The diagonal-tension theory was intended originally for beams with thin webs, in which the ratio of shear stress at failure to buckling shear stress (the so-called "loading ratio") was of the order of several hundred. Because of the various trends in design, much lower loading ratios are now frequently encountered, and it was deemed advisable to check the accuracy of the theory for low loading ratios. A series of tests was therefore made on thick-web beams, and, after some modifications, the theory was found to be applicable to beams having loading ratios less than 2.5 (Technical Note 1820). Additional test data were also provided on the failure of webs by tearing along the rivet line (Technical Note 1756).

As a continuation of the study of the buckling strength of curved elements of the airplane skin, the case of curved rectangular plates under compression with simply supported edges and a centrally located longitudinal stiffener of zero torsional stiffness was studied theoretically (Technical Note 1879). Because panels of moderate or large curvature have been found to buckle in axial compression at loads below the theoretical value, an empirical modification of the theoretical solution was suggested for use in design.

The tension skin of an airplane wing and the ribs connecting it to the compression skin have finite stiffness and will, in general, distort along with the compression skin when buckling of that skin occurs. For thin wings it may therefore be necessary to consider the stability of the wing as a whole in addition to the stability of its individual components. As a first step toward the solution of this problem, the buckling of parallel tension and compression members connected by elastic deflectional springs was studied (Technical Note 1823). This case is an idealization of the type of construction in which the rib spacing is small by comparison with the spar spacing.

The existing theory of shear lag, that is, of stress distribution in shells of the type used in aircraft construction, is based on a number of simplifying assumptions which introduce errors of unknown magnitude. The shear-lag analysis of wing covers, for instance, is based on the assumption that the transverse ribs are infinitely stiff, and it was known that this theory would lead to very large errors in the shear stresses in some cases. A simple approximate method was therefore developed (Technical Note 1728) which gives a reasonably accurate estimate of the shear stresses as shown by a series of tests.

Ultimate Strength

In designs calling for a high degree of structural stiffness, the buckling stress may be above the elastic limit for the material. An empirical correlation between such plastic buckling stress and the stress-strain curve of the material, which enabled the buckling stress to be easily computed, was reported in the previous annual report for the case of compression. The same correlation was justified theoretically by the plastic-buckling theory reported in the previous annual report. Additional experimental confirmation of this correlation has now been obtained for FS-1h magnesium-alloy sheet formed into Z's (Technical Note 1714) and for long simply supported plates of 14S-T6 aluminum alloy (Technical Note 1817). In Technical Note 1714—an empirical formula was also developed for the ultimate compressive strength of formed Z-sections and channel sections of FS-1h magnesium-alloy sheet and 24S-T

and 17S-T aluminum-alloy sheet. Some data on ultimate strength were also reported in Technical Note 1817.

The investigation of plastic buckling presented in Technical Note 1556 was extended to apply to the case of simply supported Metalite-type sandwich plates in compression (Technical Note 1822).

A series of torsional tests by Notre Dame University on stiffened structural specimens having the cross section of a D-tube were reported in the previous annual report. The tests reported covered only specimens of constant cross-sectional area. These tests have now been extended by Notre Dame University to include specimens of varying cross-sectional shapes.

The University of Alabama has investigated loads and deflections in statically indeterminate structures where one or more of the members are stressed above the proportional limit of the material. Theoretical analyses were found to agree very closely with test results of three coplanar, pin-ended structures.

At supersonic speeds, skin friction can cause large increases in the temperature of the airframe. The occurrence of this aerodynamic heating has stimulated two phases of structures research: First, the determination of the basic properties of materials at the high temperatures expected and, second, the development of methods of structural analysis that include temperature effects. Studies have proceeded on both these phases. In line with the first phase, compressive stress-strain data have been published for two aluminum alloys—24S-T3 and 75S-T6—for temperatures up to about 700° F. and for various exposure times and rates of loading (Technical Note 1837). In line with the second phase, tests were made on the plate buckling strength of H-sections at elevated temperatures (Technical Note 1806). It was found that the compressive strength of plate elements at elevated temperatures can be calculated by the same methods that apply at room temperature. It is only necessary to know the stress-strain curve for the material appropriate to the temperature under consideration.

Deformation

Multicell wings have been favored over conventional semimonocoque wings in recent high-speed designs. Work on the stress and strength analysis of such construction is proceeding. A paper has been published (Technical Note 1749) devoted to the determination of relations between the cellular shear flows and the rates of cell twist, and cases have been included in which the rate of twist varies from cell to cell. The relations apply to uniform beams consisting of identical cells. Included in the paper are an analysis of the shear flow associated with spanwise rate of change of antielastic

curvature and also a formula relating the torsional stiffness to the number of cells.

The analysis of plate structures loaded beyond the elastic range requires a knowledge of the polyaxial plastic stress-strain relations of the material. A variety of theories has been proposed for these plastic stress-strain relations. Some preliminary experiments of a crucial character have led to the conclusion that none of the existing theories is entirely satisfactory and an attempt has been made to devise one in better agreement with experiment. As a result of this effort, a theory for the plastic stress-strain relations has been devised which constitutes a radical departure from the main currents of thought on plasticity (Technical Note 1871). The formulation of the theory was guided mainly by the physical considerations with respect to the mechanism of plastic deformation which is assumed to be slip. The theory is in better agreement with the aforementioned experiments than previously existing theories, but more extensive experimental checks must be made before its validity can be fully assessed.

In dynamic and aeroelastic wing analyses, relationships between load and deflection are necessary. Load-deflection relationships that give the deflections at a number of discrete stations in terms of the loading intensity can conveniently be expressed by any one of several matrix methods. The use of these methods and a comparison of their accuracy are discussed in Technical Note 1827. In addition, it is shown how the accuracy of these methods may be improved, and the calculation time reduced, by the use of weighting matrices.

Structural Efficiency

The necessary condition that the wing surface of modern high-speed aircraft remain smooth under high loads has led to the consideration of the sandwich plate as a substitute for sheet-stringer construction. Sandwich plates consist of two thin sheets of material separated by a low-density, low-stiffness core which, though contributing little to the strength of the plate, serves to increase tremendously the flexural stiffness of the load-carrying faces. The increase in flexural stiffness is somewhat offset, however, by deflections due to shear which become appreciable because of the low stiffness of the core.

One type of sandwich called Metalite employs a core of balsa wood with the grain normal to the metal faces. The compressive buckling of this type of sandwich has been investigated theoretically and checked against available test data for the case of flat rectangular plates with simply supported loaded edges and clamped unloaded edges (Technical Note 1886) as well as for the case of all edges simply supported (Technical Note

1822). The case of shear buckling of long simply supported plates has also been investigated theoretically (Technical Note 1910).

The Polytechnic Institute of Brooklyn has also investigated the bending and buckling of rectangular sandwich plates. Equations were developed for calculating the deflections and buckling load of rectangular sandwich panels under transverse loads and edgewise compression. The equations were solved for the case of a simply supported plate under compression and the results have been presented in graphical form.

Vibration Characteristics

The natural vibration modes and frequencies of airplanes often form the basic parameters in an analysis of the response of an airplane to dynamically applied forces. A theoretical solution for these vibration modes and frequencies must of necessity be made by some approximate method because of the complexity of the airplane structure. One such approximate method is presented in Technical Note 1747 for the general problem of coupled bending and torsional vibration of a nonuniform wing mounted at an angle of sweep on a fuselage. This method makes use of the energy approach in conjunction with the natural bending and twisting modes of an unswept uniform beam to derive the characteristic equations describing symmetrical and antisymmetrical modes of vibration of the wings and fuselage. Numerical examples are also given and the results show that a desired mode and frequency may be calculated with good accuracy using low-order determinants.

Among the factors ordinarily neglected in the bending-vibration analysis of wings are (a) the additional flexibility of the wing due to shear deformation of the spars and (b) the additional inertia loading due to the angular accelerations of the wing elements. In order to assess the importance of these two factors, they were included in a theoretical analysis of the natural frequencies of uniform beams, with various boundary conditions, in bending (Technical Note 1909). Both the shear deformation and the rotary inertia were found to lower the natural frequencies. Charts were provided to permit a quantitative evaluation of the lowering of the frequencies.

Research Equipment

During the past year a unique combined-load testing machine has been placed in operation at the Langley Aeronautical Laboratory. This machine permits application of forces and moments about three perpendicular axes simultaneously. The machine is greatly facilitating the study of structures under various combinations of axial loads, shears, and moments.

SUBCOMMITTEE ON AIRCRAFT STRUCTURAL MATERIALS

The majority of the investigations on aircraft structural materials have been carried out by contracts with universities and other nonprofit scientific organizations. These investigations have complemented the program on materials for power plants.

Fatigue of Metals

A commonly recognized gap in information about the fatigue behavior of aircraft materials is the lack of comprehensive test data on one lot of any single material. At the same time, there is a serious lack of strictly comparable fatigue test data for competitive materials. Therefore plans were made to investigate rather fully the fatigue behavior of each of three metals commonly used in airframe construction: 24S-T and 75S-T aluminum alloys and 4130 steel. It was planned to obtain data on a number of items including:

(1) Fatigue studies of unnotched sheet over the full range from completely reversed stresses to stresses varying about a high mean tensile stress.

(2) Fatigue studies of notched specimens covering a range of notches and, for each type of specimen, a range of stress conditions.

(3) Fatigue damage studies.

In the 1948 annual report, it was pointed out that Battelle Memorial Institute had completed investigations of most of item (1). During the past year Battelle Memorial Institute has continued its investigations primarily under item (2) along with some extensions of item (1) that appeared desirable.

For the studies under item (2) it was necessary to design some standardized fatigue specimens with stress-concentration factors of known magnitude. Holes, notches, and fillets have been widely used for this purpose because they represent, to some extent at least, practical cases of stress concentration. It was found, however, that there was insufficient information available on the stress concentrations produced by notches and fillets to cover the range that was considered important. Photoelastic investigations were therefore initiated in order to provide the necessary information.

The Illinois Institute of Technology conducted these photoelastic investigations and determined factors of stress concentration for both grooves and fillets in bars under tension, as well as distributions of principal stresses along the section of symmetry through the grooves.

The Langley Laboratory has studied the effect of plasticity on stress concentration. In the vicinity of holes, notches, and other discontinuities of structure, high-

stress peaks are developed when a load is applied. If the peak stress is beyond the elastic limit of the material, there will be local plastic yielding; after release of the load, residual stress will remain in the structure, and the peak stress caused by successive applications of the load will be decreased. This phenomenon was studied by tests on a series of large panels with round holes (Technical Note 1705). The results are expected to be useful in developing methods of fatigue analysis.

Sandwich Materials

The Forest Products Laboratory has continued investigations of sandwich materials. They have completed an investigation of strength and elastic properties of honeycomb-type core materials fabricated from resin-impregnated rayon-mat fabrics. The honeycomb core materials fabricated from resin-impregnated rayon-mat fabric do not appear to be better over-all core materials for use in sandwich construction than resin-impregnated paper honeycomb cores of equal density. However, for sandwich applications requiring a high-tensile-strength core, the rayon-mat honeycomb core material would be more efficient than a paper core of equal weight.

The Forest Products Laboratory has conducted preliminary tests on adhesives for bonding sandwich constructions of aluminum facings on paper honeycomb cores. A total of 14 gluing processes was evaluated by tension tests on specimens of 1-inch aluminum cubes bonded to a resin-impregnated paper honeycomb core.

The Forest Products Laboratory has also completed an analysis of the shear strength of honeycomb cores for sandwich constructions. The analysis was undertaken to arrive at a mathematical formula by which the shear strengths of honeycomb core materials could be calculated. It was assumed that each cell wall acted independently, like a plate supported and loaded along its edges, and that the shear strength of the honeycomb would be determined by the failing stress of these plates. A similar analysis had been made by the Forest Products Laboratory in the past on the compressive strength of honeycomb cores.

Magnesium-Cerium Wrought Alloys

A program on the development of magnesium-cerium wrought alloys at Battelle Memorial Institute under NACA sponsorship showed that the wrought alloys have substantially lower creep resistance than the cast alloys of similar composition, and that the effect of heat treatment was far greater than the effect of variations of alloy compositions which were studied. This program was previously reported in the 1947 annual report.

Inasmuch as previous investigation has indicated that magnesium-cerium alloys in the wrought condition possess an unusual combination of low density and rela-

tively high mechanical properties for elevated-temperature service up to at least 600° F., the NACA has supported additional investigation of these alloys at Battelle Memorial Institute during the past year. The investigation has included both fundamental studies and alloy development because it was felt that the development of improved compositions would be facilitated if there were a better understanding of the factors determining the creep resistance of the alloys.

SUBCOMMITTEE ON AIRCRAFT LOADS

Loads on Wings

The large variations in wing configurations which have accompanied the increased speed of modern airplanes and missiles have made it necessary to provide more general methods for computing span loading than those that were heretofore available. Before any of the newly developed general methods can be used with confidence, results obtained with them must be compared with experimentally determined distributions. Two studies conducted at the Ames Laboratory have permitted such comparisons. In one of these studies the pressure distribution over a highly swept wing was determined for several angles of attack at supersonic speed, and in another study the load distribution on a similar wing in combination with a body was determined for a range of angle of attack through a range of supersonic speed. These results showed that the theory used predicts the loading due to angle of attack reasonably well, particularly at the higher Mach numbers investigated.

In another investigation at the Ames Laboratory, the load distribution was determined for a moderately swept wing at speeds up to a Mach number of 0.94. The results, when compared with the load distribution predicted by theory, were found to be in good agreement.

An exact knowledge of the maximum lift obtainable from a wing and its variation with speed and with pitching velocity has become more important with the increases in wing loading and in operations at high altitude. Maximum lift is also a factor not only in the loads which may be imposed on the airplane but also in the turning radius of missiles and the maneuverability of airplanes. A study of this problem was conducted at the Langley Laboratory using an airplane model which could be pitched at various velocities through an angle-of-attack range from zero lift through maximum lift, and measurements were made of the increase in maximum lift with pitching velocity. These results were compared with similar results obtained in flight on the actual airplane to establish the validity of this method. The results have been reported in Technical Note 1734.

A related study has been conducted at the Ames Laboratory in which flights were made with a pursuit airplane to determine the effect of rate of change of angle of attack on the maximum lift coefficient over a range of Reynolds number and up to a Mach number of 0.50. This study has indicated that the rate of increase of maximum lift coefficient with increasing abruptness of the stall is significantly affected by Reynolds number as well as Mach number. Experiments so far on this problem have been limited mainly to subsonic and low transonic speeds. Pending the availability of data at high transonic and supersonic speeds, a method has been derived by which the over-all forces on an airfoil operating in flow with detached shock waves may be calculated. This method employs a concept of a limiting pressure based on available pressure-distribution data and assumes a shape of the shock front. While the method enables the maximum lift coefficient to be calculated, it can also be used to calculate the lift-drag curve in all conditions where the shock wave is detached. Comparisons show that the method agrees well not only with experimental data but also with the results obtained with the linear theory for the case where the shock wave is attached at the leading edge.

The increased speed of aircraft has also necessitated thinner and more flexible wings so that it has been necessary to include the effects of aeroelasticity in design calculations. Thus the problem of predicting span loading has become more complex than it was a few years ago. A number of studies has been carried out on this problem and, as a result, a method has been developed by which the span loading of flexible wings of arbitrary plan form and stiffness may be determined. This work, reported in Technical Note 1876, so systematizes the problem that calculations may be made in a routine manner.

Wing flexibility has also affected the related problem of the lateral control available with a given wing construction. Wing divergence and aileron reversal, which 5 years ago were mainly problems of academic interest, have now assumed major proportions. Since span loading and lateral control are linked together, the methods developed for predicting span loading have been extended to permit calculations of the effects of structural flexibility on lateral control of wings of arbitrary plan form and stiffness. This work has also been systematized so that calculations are routine.

Theoretical studies of the span load distribution on swept and low-aspect-ratio wings have been extended to permit prediction of the effects of wing twist. This work has been reported in Technical Note 1772 in which the theoretical development is given, together with all factors required for its rapid application. The method has been applied to the study of the effects of wing twist

and the aerodynamic characteristics of some typical swept wings.

Studies have been conducted along both experimental and theoretical lines to provide information relating to maneuver loads on aircraft. In one investigation, reported in Technical Note 1729, the wing and tail loads of a fighter-type airplane were determined from electric strain-gage measurements. These tests extended to a Mach number of 0.8. The results in general support the conclusions found in previous pressure-distribution studies.

Loads on Tails

Research on maneuvering tail loads has been continued. In the investigation reported in Technical Note 1729 the tail loads on a fighter-type airplane were determined in flight from electric strain-gage measurements at speeds up to a Mach number of 0.8. The results of this study verify the fact that with an accurate knowledge of the tail-load parameters, such as may be obtained from carefully conducted wind-tunnel tests, an accurate calculation of the tail loads in maneuvers can be made. The parameters required are the pitching-moment coefficient, the location of the aerodynamic center, and the pitching acceleration.

As an approach to the problem of predicting tail loads at supersonic speeds, a study has been conducted by the Lewis Laboratory in which a theoretical method for obtaining the aerodynamic forces acting on a thin wing has been applied to determine the lift and moments acting on a rectangular tail surface due to linear and spanwise parabolic upwash distributions. This study has been reported in Technical Note 1736.

Loads on Control Surfaces

The investigation in the Langley 19-foot pressure tunnel of the loads on leading-edge flaps on swept wings has been continued. Pressure-distribution measurements over a half-span leading-edge flap on two wings having NACA 64-112 airfoil sections have been made. Both wings were equipped with a half-span split flap and the 42° sweptback wing was investigated in conjunction with a circular fuselage.

As a part of the Committee's continuing program of research on the determination of the aerodynamic characteristics of various airfoil sections, an investigation of the pressure distribution over an NACA 66,1-115 airfoil section with a 20-percent-chord flap has been made through a Mach number range to 0.75 in the Langley 8-foot high-speed tunnel. Two flaps, one having the true airfoil contour and one having a 30° trailing-edge angle, were investigated. The results of this investigation, reported in Technical Note 1596, provide additional information on the effects of variation

of the trailing-edge angle on the effectiveness of flaps or ailerons at high speeds.

Loads on Bodies and Wing-Body Arrangements

One loading problem which has become of major importance is the determination of the division of load between the airplane wing, tail, and body. To assist the designer in more accurately dividing the loads, an analysis has been made of all the available data on the effects of wing-fuselage-tail and wing-nacelle interference on the distribution of the air load among the components of the airplane.

A theoretical approach has also been made to the load-distribution problem for the case wherein the wing is relatively small in relation to the size of the body. This configuration is typical of missiles. Using the assumptions that the body is slender and the wing is of low aspect ratio, theoretical relations have been developed for the prediction of the effects of mutual interference between a body and either a simple or a cruciform wing. The theory and results of some calculations are presented in Technical Notes 1662 and 1897.

Pressure coefficients at local Mach numbers reaching supersonic speeds have been determined for the flow over a prolate spheroid and a wing having an NACA 65-010 section in the Langley 8-foot, high-speed tunnel. The values of pressure coefficient and Mach number over the spheroid were compared with theory and a study was made of the development of a supersonic flow pattern.

Pressure distributions have also been obtained on the wings and fuselage of a scale model of a research-type airplane through a speed range to high subsonic Mach numbers. These data are of direct use in providing basic structural loading information.

The effects of a nacelle on the aerodynamic characteristics of a swept wing and the effects of sweep on this wing have been investigated in the Langley 16-foot, high-speed tunnel up to Mach numbers of 0.61 for the wing-nacelle combination and 0.70 for the wing alone. Extensive pressure measurements, published in Technical Note 1709, were made in the course of the investigation to provide a basis for detailed study of the interference effects.

As part of a general study to find the source of wing failures following installation of a wing-tip tank on a service airplane, an investigation was made in the 40-by 80-foot wind-tunnel section at the Ames Laboratory to determine the effect of wing-tip tanks on the distribution of wing load and on the distribution of wing bending and twisting. Complete pressure distributions were obtained over the wing and wing-tip-tank combination of the airplane.

Gust Loads

A series of calculations of the transient response

induced by gusts in airplane wings has been made and analyzed. These calculations were made for the purpose of comparing the response of present-day large transport airplanes with that of an older transport airplane, which has proved itself to be satisfactory from the standpoint of gust experience. On the basis of the method of calculation used and the conditions selected for analysis, it is indicated that the newer airplanes show appreciably greater dynamic response in gusts than did the older reference airplane and that increasing the forward speed or the operating altitude results in an increase of the dynamic response for the gust with a gradient distance of 10 chords. The results were also used in studying the advisability of including a transient-stress requirement for gust loads in the civil air regulations of the International Civil Aviation Organization.

One of the problems associated with the design of airplanes having wings with large angles of sweep is the prediction of gust-load factors. Previous research on this problem had been confined to an airplane model with a 45° sweptback wing. During the past year, investigations in the Langley gust tunnel of the effect of wing sweep on the gust-load factor have been extended to include a 45° sweptforward wing and a 30° sweptback wing. The results, presented in Technical Notes 1717 and 1794, support the previous findings that the maximum acceleration increment of an airplane with a swept wing will be generally less than that for an airplane with an unswept wing under the same set of flight conditions.

A cooperative flight investigation was undertaken by the NACA and the All Weather Flying Division of the U. S. Air Force at Clinton County Air Force Base, Wilmington, Ohio, for the purpose of determining the effects of compressibility on gust loads. This is believed to be the first attempt to obtain aerodynamic information by the statistical comparison of airplane reactions. Test data over a Mach number range of 0.25 to 0.68 were obtained from flights of two similar jet-propelled airplanes in rough air. The data and analysis presented in Technical Note 1937 indicate no compressibility effects on the over-all gust reactions of the airplane tested within the limits of the data obtained.

Technical Note 1753 presents the results of an investigation made in the Langley gust tunnel to determine the effectiveness of a fixed spoiler in reducing gust-load factors. The results indicate that the model undergoes approximately the same maximum acceleration in a sharp-edge gust with or without the spoilers. In a gust having a finite gradient, however, a reduction of 30 percent in the maximum acceleration increment was realized through the use of the fixed spoilers.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

Flutter of Wings and Control Surfaces

A comprehensive experimental and theoretical study of the effects of wing sweepback on the flutter characteristics of cantilever wings throughout the subsonic speed range has been made. The wings used in the experiments included a large range of sweepback angle and aspect ratio. Comparison of the theoretical results with the experiments indicates that the theory will satisfactorily predict the effects of sweep on the flutter characteristics of uniform cantilever wings of moderate aspect ratio.

Investigations of the flutter of wings of various shapes and thickness ratios at transonic and supersonic speeds have also been made utilizing testing techniques of wind tunnels, freely falling bodies, and low-acceleration, rocket-propelled vehicles. The results of these investigations have been used to evaluate the applicability of existing theoretical methods for calculating flutter characteristics at supersonic speeds.

An investigation of the flutter characteristics at supersonic speeds of models of the wing panels of a transonic research airplane has been made by the Langley pilotless aircraft research division using rocket-propelled models. The models used in this investigation aerodynamically and structurally simulated the full-scale wing panels. The structural parameters were varied over a small range so as to yield design flutter speeds greater than, equal to, and less than the design flutter speed of the full-scale wing panel.

The effect of aspect ratio on the undamped torsional oscillations of a finite rectangular wing in a supersonic stream has been reported in Technical Note 1895. The velocity potential and aerodynamic-torsional-moment coefficients based on the linearized equations of motion for small disturbances are derived for a rectangular wing by means of appropriate distributions of moving sources and doublets. The coefficients thus derived are combined with a mechanical-damping coefficient to study the effect of aspect ratio. The results show that decreasing the aspect ratio of the wing has a highly stabilizing effect on the undamped torsional oscillations.

A theoretical approach to the prediction of flows around and forces on an oscillating airfoil of finite span has been undertaken by the Massachusetts Institute of Technology under the sponsorship of the NACA. The aim of this study is the development of a theory which incorporates simultaneously the effects of three-dimensionality of the flow and compressibility of the fluid. An exact solution of this problem presents great difficulties and the work therefore is directed toward an approximate theory which is valid provided the aspect

ratio of the lifting surface is not too small. Earlier work has included the problem of two-dimensional incompressible flow as a special case. The present work generalizes these results so as to take account of compressibility in the supersonic range and describes a method of solution for the three-dimensional problem.

Aileron flutter or "buzz" at transonic speeds has continued to be a serious problem, and considerable research effort has been devoted by the NACA to its solution. One investigation, utilizing both rocket-propelled and wind-tunnel models, has been made to determine the effects of mechanical damping in the control system on the flutter characteristics of dynamically similar scale models of the ailerons of a research-type airplane. The results of this investigation show that the occurrence of aileron "buzz" is critically dependent upon the amount of damping in the aileron control system and also tend to point up the critical nature of aeroelastic instability of wing-aileron combinations at high speeds.

An investigation of the effects of altitude on the flutter characteristics of an aileron at high speed has been made in the Langley 4.5-foot flutter research tunnel. The effects of altitude were simulated by variation of the tunnel pressure from 1 to $\frac{1}{3}$ atmosphere which corresponds to an altitude variation of from sea level to approximately 38,000 feet.

An investigation has been made to determine the feasibility of studying aileron "buzz" by the wing-flow method, using two semispan models differing in airfoil section. The half-span, quarter-chord, mass-balanced ailerons used on both models were unrestrained except for bearing friction. Aileron "buzz" was obtained for both models for a small range of Mach number near 0.90.

Flutter of Wings with Concentrated Weights

The flutter characteristics of a wing are greatly affected by the mass and location of concentrated weight such as fuel tanks, engines, and bombs. An experimental program on the effect of heavy concentrated weights on the flutter speed and frequency of a straight cantilever wing was previously reported in Technical Note 1594. These same wing-weight combinations have been analyzed by a method involving the direct solution of the differential equations of motion by operational methods in Technical Note 1848. The theoretical two-dimensional oscillating air forces were used in the analysis. The theory accurately predicted the true flutter speed even when that speed was critically dependent upon weight position and upon changes in flutter mode. This agreement indicates that the theoretical air forces were adequate for these experimental conditions and that the structural representation of the problem was accurate. Since this differential-equation method is difficult to apply to an actual wing having taper and

many concentrated weights, a more practical method using these same experiments and the same theoretical oscillating air forces was evolved. This work is reported in Technical Note 1902. The method involves the selection of a few chosen uncoupled modes of static vibration as generalized coordinates for the flutter analysis. Since the differential-equation method of Technical Note 1848 gave good agreement with experiment, inaccuracies of the simplified method are attributable to the approximations in the structural representation. It was found that, for the cases with the weight located forward on the chord, results obtained with the mode analysis were above the experimental value (that is, on the dangerous or unconservative side); whereas, for cases with a rearward location of the weight, the theory predicted too low a flutter speed. This work indicates that great care must be used to select a sufficient number of modes when analyzing cases with large mass coupling and with forward weight positions.

The mutual effect of large streamlined bodies, such as external fuel tanks, on the oscillating air forces of wings and bodies is not known. In order to gain some insight into the magnitude and effect of these air forces on the flutter characteristics of a wing, the Langley 4.5-foot flutter research tunnel was used in an investigation in which the mass and moment of inertia of a concentrated weight were held constant while the shape of the weight was varied. Two general contours of the weight were employed: One a streamlined body and the other a nonstreamlined body. The results of this investigation show only minor changes in flutter speed and flutter frequency with a change in the aerodynamic shape of the body.

The experimental investigation of the effects of concentrated weight on the flutter characteristics of unswept wings previously reported upon has been extended to the case of sweptback wings. Each wing carried a single weight, at a series of spanwise positions on the leading edge and midchord. The investigation covered sweepback angles of 0°, 45°, and 60°. The data obtained

from this investigation should be of considerable aid to the airplane designer in choosing the optimum location, from flutter considerations, of such units as engines and external fuel tanks.

Fuselage Vibration Due to Propeller

Several instances of structural failures of the fuselage in the vicinity of the propeller plane of rotation on multiengine airplanes have been reported. It was reasoned that these failures were the result of fatigue of the fuselage material resulting from propeller-excited fluctuation in air pressures on the fuselage side. A theoretical and experimental investigation has been made of the characteristics of the pressure field in the vicinity of the tip of a rotating propeller. The results of this investigation as reported in Technical Note 1870 show that the shape of the propeller blade was not significant in exciting fuselage vibration, but that the number of blades, the power, the tip Mach number, and the ratio of tip clearance to propeller diameter were significant. It was found that, for a given power, increasing the tip clearance and increasing the number of blades were of greatest importance in reducing fuselage vibration.

Towed Bodies

Previous analyses of the stability of towed bodies stabilized by fins have generally assumed that the towing cable remained steady. These theories failed to predict the violent motion of these bodies and the oscillations of the cable which have been observed above a certain airspeed. A theoretical investigation was therefore made of the stability of oscillations of the cable and the results are presented in Technical Note 1796. This theory concludes that the violent oscillations may be attributed to cable oscillations which originate near the airplane and are amplified by aerodynamic forces as they travel down the cable. Means are discussed for increasing the speed at which these oscillations become violent.

AIRCRAFT OPERATING PROBLEMS RESEARCH

The research in the field of aircraft operating problems conducted by the NACA is concerned with those problems that impair aircraft performance or are related to the inherent safety of the aircraft itself. The major efforts of the NACA in this segment of its research activities are on the investigation of turbulence, icing, and fire prevention. The research on atmospheric turbulence is centered at the Langley Aeronautical Laboratory. The research on icing and fire pre-

vention is centered at the Lewis Flight Propulsion Laboratory. A limited part of the icing research program is under investigation at the Ames Aeronautical Laboratory. Contracts for research in these fields have also been placed with several universities. This work is guided by the Committee on Operating Problems and its subcommittees, the Subcommittee on Meteorological Problems, the Subcommittee on Icing Problems, and the Subcommittee on Aircraft Fire Prevention.

COMMITTEE ON OPERATING PROBLEMS

Effect of Flight Speeds on Aircraft Operation

The analysis of the data obtained in the V-G program is being continued to obtain information on the imposed flight loads, operating speeds, and route roughness. The results of the records obtained from V-G recorders during the prewar period on three different commercial-transport-airplane types are presented in Technical Notes 1733, 1754, and 1783. An analysis of the first postwar sample of V-G data obtained from commercial-transport operations indicates that, on the average, the positive and negative gust-load-factor increments may each be exceeded once in about 5.8×10^5 flight miles and the never-exceed speed may be exceeded once in about 5.0×10^5 flight miles which is in agreement with past experience. These results indicated a trend toward higher imposed flight loads and apparent increased gust experience for postwar transport airplanes.

Pilot Escape

The problem of escape from airplanes has become very acute with the increases in speed recently achieved. A detailed study with free-flight models has been made of pilot escape by use of nose sections that can be jettisoned.

Noise

In the course of the investigation of airplane noise, a large group of mufflers of varied design were evaluated and reported in Technical Notes 1688 and 1838. The results indicate that the types of available commercial mufflers investigated were relatively ineffective and that very little information is readily available for effective muffler design. Theoretical and experimental investigations are being continued to determine the basic fundamentals of aircraft-muffler design.

Ditching

In cooperation with the Civil Aeronautics Administration, ditching investigations of all of the four-engined transport-type aircraft used in scheduled commercial operations have been made. These investigations were conducted on the monorail in Langley tank No. 2 using dynamically similar models. In addition, the models of the various aircraft had scale-strength bottoms and flaps in order that the effect of damage occurring during a ditching would be simulated. The ditching behavior of the transports investigated was generally similar and was better than the ditching behavior of bombers because there is less damage and the decelerations are lower.

One airplane ditching that occurred during the year verified the fact that transport-type aircraft of the types investigated can safely be ditched.

SUBCOMMITTEE ON AIRCRAFT FIRE PREVENTION

The Subcommittee on Aircraft Fire Prevention has completed the formulation of an experimental program that was started during the past year. The initial phases of the research program are currently under way.

Review of Fire Records and Survey of Fire Research

As an aid in establishing the aircraft-fire-prevention research program, an extensive bibliography of existing literature has been collected and an analysis has been made of the records of aircraft crashes accompanied by fire. Although the primary purpose for reviewing the aircraft fire records is to establish the fire research program, it has become apparent that careful consideration has to be given to a method whereby data are collected from crashes occurring in normal aircraft operation.

Rate and Spread of Aircraft Fires

In order to gain an insight into the rate and spread of an aircraft fire following a crash, two experimental programs have been initiated. In the first program, the propagation of the flame along an air stream over a flat surface, in a duct, and over the external surface of a streamlined body is being investigated for combustibles common to current transport aircraft. Obstructions in the air stream and roughness on the surfaces are being used to simulate the flow of air in and around typical airplane components. Variations in the combustible and form of the combustible at sea-level temperature and pressure are also being studied.

The second program includes the use of war-surplus transport-type aircraft in simulated take-off or landing incidents that usually result in fire. The airplanes are being extensively instrumented so that data will be obtained on the time history of the events following impact, including the recording of ignition and spread of fire.

Inflammability of Aircraft Materials

In addition, work has been continued to establish practical concepts of ignition sources and inflammability to determine the state of development of less inflammable lubricants and hydraulic fluids in order to establish guides for undertaking research leading to the discovery of new compounds or additives, and to study the physics and chemistry of aircraft fire extinguishing.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Because the operation of airplanes in regions of severe atmospheric turbulence reduces the effective useful life of the airplane, emphasis has been given to the

forecasting and the detection of regions of atmospheric turbulence.

Past work has indicated that the horizontal temperature variations and height of convective activity give a measure of the maximum effective gust velocities in clouds in the temperate region. In order to check this indicated relation for other conditions, an analysis is presented in Technical Note 1917 of the relations between the horizontal temperature variations and the maximum observed effective gust velocities for the data obtained during operations of the United States Weather Bureau thunderstorm project in Florida and Ohio. The results indicate that the relation, when extended to include frontal conditions, appears useful for forecasting the intensity of turbulence for thunderstorms in temperate regions. The relation does not appear useful, however, for forecasting the intensity of turbulence in subtropical regions.

In order to evaluate radar as a means of detecting turbulence, acceleration measurements and air-borne radar observations were taken during a transcontinental flight of an American Airlines airplane. Although sufficient data were not obtained to give adequate results for application to airline operations, the analysis indicated that some reduction in the turbulence experienced, and a consequent reduction in the risk of encountering the larger gust velocities, may be obtained by avoiding portions of clouds giving a radar echo.

SUBCOMMITTEE ON ICING PROBLEMS

The hazard of ice formation on airplanes involved in all-weather operations has received continued study. Work on the research program was conducted for the most part at the Lewis Flight Propulsion Laboratory. Previous work at the Ames Aeronautical Laboratory and contract research by the University of California at Los Angeles were analyzed and reported during the fiscal year.

Meteorological Characteristics of the Icing Cloud

The study of the important characteristics of icing clouds was continued by means of specially instrumented airplanes flown through icing conditions. Data obtained with the same airplanes in successive years show (Technical Note 1793) unexplainable annual variations in mean values of icing conditions. Analysis of data taken over most of the northern United States (Technical Note 1904) gave information on the regional variations of important parameters. Recommended values of meteorological factors to be considered in the design of aircraft ice-prevention equipment were established and presented in Technical Note 1855. This report extends the previous estimates of probable maximum and normal icing conditions to cover as completely

as is presently possible all conditions likely to be encountered.

Investigation of Methods of Ice Protection

Wings and empennages. Two important factors influencing the design of ice-prevention equipment are the amount of water striking the wings and the area on which it impinges. In order to provide information on these factors, a theoretical investigation was undertaken to study the paths the water droplets describe in approaching an airfoil section. Using a differential analyzer, these paths were calculated for a number of airfoil shapes by the University of California at Los Angeles for the NACA. As a result of an analysis of the data supplied by UCLA, a semiempirical method was developed for computing the region covered by the droplets and the amount of water striking an airfoil section of any arbitrary shape.

Propellers. In order to provide further information on the effects of ice accretions on propeller performance, flight tests were conducted in natural icing conditions and measurements were made of the performance changes resulting from a number of formations. A study of these data, together with similar data previously obtained, indicated that, with no ice protection, performance losses normally would be low and that large performance losses would be rare.

Jet engines. Ice-protection methods under investigation include inertia separation of freezing water from the air before it reaches the engine, heating the incoming water-air mixture above freezing by taking hot gas from the combustion chambers and injecting it into the air at the duct entrance, and heating the critical surfaces of the duct and engine to prevent freezing of impinging water.

Continued studies of the mixing and the depth of penetration of high-velocity jets of hot gas injected at right angles to an air stream have provided data for selecting the size and the arrangement of orifices for a hot-gas bleedback ice-protection system. Adopting these practices, small percentages of gas at combustion-chamber discharge conditions have successfully prevented icing in simulated icing tests of a full-scale axial-flow turbojet engine. In further investigations in the Lewis icing research tunnel, using two-thirds-scale models of three different types of inlet, the required percentage of bleedback was determined for a wide range of icing conditions and the uniformity of mixing with proper orifice arrangements was demonstrated. The hot-gas bleedback method proved to be a quick and effective way of providing complete ice protection on suitably designed installations in which compressor air is not required for cabin pressurization.

Analysis shows that heating all the critical surfaces on which freezing water will impinge will provide ice protection with negligible thrust loss because the optimum shape of inlet can be used and the engine air is heated only a negligible amount. With this method, the duct entrance and walls would be heated by internal hot-gas ducts, whereas the engine struts, the inlet guide vanes, and the accessory fairing would be heated by internal electrical-resistance elements or by leading hot air through hollow passages in these parts. Preliminary analyses and laboratory tests have been completed on a method of heating compressor guide vanes and first-stage rotor blades by means of electrical eddy currents induced in these parts by alternating electromagnetic excitation induced by the rotor, which is modified to act as a multiple generator.

Light-airplane induction systems. A laboratory investigation demonstrated that safe operation of the induction systems of light airplanes can be accomplished with cold ram air by using currently available equipment provided subcooled water and snow are excluded by an inertia-separation inlet with a filter and the carburetor throttle valve is heated to above freezing whenever low power settings are used at air temperatures below 40°

F. Pressure-injection carburetors, similar to those used on transport airplanes, gave reliable metering under icing conditions when erratic performance of a natural-aspirating carburetor would have caused engine power failure. Simple engine-oil-heated jackets around the intake distribution manifolds successfully prevented ice formations that reduced engine air flow in unheated systems (Technical Note 1790).

Nonplugging fuel-tank vents. An investigation made of the icing characteristics of a recessed underwing fuel-tank vent led to a special adaptation for this purpose of the NACA flush inlet with divergent ramp side walls. This type-vent was subjected to severe icing conditions when mounted at approximately 70 percent of the chord on a wing undersurface at high angles of attack and showed positive vent-tube pressures without plugging for 60 minutes of icing (Technical Note 1789). This development represents a practical solution to the problem of safety venting bladder-type fuel cells to prevent collapse due to negative pressure or the stoppage of fuel flow when ice forms at the vent. The new vent principle should find other aircraft applications, such as oil-tank vents.

RESEARCH PUBLICATIONS

TECHNICAL REPORTS

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| <p>No.
863. Wing Plan Forms for High-Speed Flight. By Robert T. Jones.</p> <p>864. Effects of Temperature Distribution and Elastic Properties of Materials on Gas-Turbine-Disk Stresses. By Arthur G. Holms and Richard D. Faldetta.</p> <p>865. Method for Calculating Wing Characteristics by Lifting-Line Theory Using Nonlinear Section Lift Data. By James C. Sivealls and Robert H. Neely.</p> <p>866. An Analysis of the Full-Floating Journal Bearing. By M. C. Shaw and T. J. Nussdorfer, Jr.</p> <p>867. A Theoretical Investigation of Hydrodynamic Impact Loads on Scalloped-Bottom Seaplanes and Comparisons with Experiment. By Benjamin Milwitsky.</p> <p>868. Summary of Lateral-Control Research. By Langley Research Department—Compiled by Thomas A. Toll.</p> <p>869. Isolated and Cascade Airfoils with Prescribed Velocity Distribution. By Arthur W. Goldstein and Meyer Jerison.</p> <p>870. Tank Investigation of a Powered Dynamic Model of a Large Long-Range Flying Boat. By John B. Parkinson, Roland E. Olson, and Marvin I. Haar.</p> <p>871. Determination of Elastic Stresses in Gas-Turbine Disks. By S. S. Manson.</p> <p>872. Theoretical Study of Air Forces on an Oscillating or Steady Thin Wing in a Supersonic Main Stream. By I. E. Garlick and S. I. Rubinow.</p> <p>873. High-Altitude Flight Cooling Investigation of Radial Air-Cooled Engine. By Eugene J. Manganiello, Michael F. Valerino, and E. Barton Bell.</p> | <p>No.
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920. The Development and Application of High-Critical-Speed Nose Inlets. By Donald D. Baals, Norman F. Smith, and John B. Wright.
921. Theoretical Symmetric Span Loading at Subsonic Speeds for Wings Having Arbitrary Plan Form. By John De-Young and Charles W. Harper.

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1143. (Supplement) Charts for Determining the Characteristics of Sharp-Nose Airfoils in Two-Dimensional Flow at Supersonic Speeds. By H. Reese Ivey, George W. Stickle, and Alberta Schuettler.
1430. A Theoretical Study of the Dynamic Properties of Helicopter-Blade Systems. By H. Reissner and M. Morduchow.
1446. Theory of the Inlet and Exhaust Processes of Internal-Combustion Engines. By Tsung-chi Tsu.
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1454. An Investigation of Aircraft Heaters. XXX—Nocturnal Irradiation as a Function of Altitude and Its Use in Determination of Heat Requirements of Aircraft. By L. M. K. Boelter, H. Poppendiek, G. Young, and J. R. Anderson.
1457. Overbalancing in Residual-Liquidation Computations. By Alfred S. Niles.

¹ The missing numbers in the series of technical notes were released before or after the period covered by this report.

- No.
1493. A Statistical Study of Wave Conditions at Four Open-Sea Localities in the North Pacific Ocean. By L. A. Harney, J. F. T. Saur, Jr., and A. R. Robinson.
1584. A Metallurgical Investigation of a Contour-Forged Disc of EME Alloy. By E. E. Reynolds, J. W. Freeman, and A. E. White.
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1696. Chordwise Pressure Distributions on a 12-Foot-Span Wing NACA 66-Series Airfoil Sections up to a Mach Number of 0.60. By Nancy E. Wall.
1697. The Effects of Compressibility on the Lift, Pressure, and Load Characteristics of a Tapered Wing of NACA 66-Series Airfoil Sections. By Morton Cooper and Peter F. Korycinski.
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1715. Moller Diagrams for Air Saturated with Water Vapor at Low Temperatures. By Reece V. Hensley.
1716. Tables of Hypergeometric Functions for Use in Compressible-Flow Theory. By Vera Huckel.
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1717. Gust-Tunnel Investigation of a 45° Sweptforward-Wing Model. By Harold B. Pierce.
1719. Flight Measurements of Buffeting Tail Loads. By Allen R. Stokke and William S. Aiken, Jr.
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 1931. Design Method for Two-Dimensional Channels for Compressible Flow with Application to High-Solidity Cascades. By Sumner Alpert.
 1935. Methods for Determining Frequency Response of Engines and Control Systems from Transient Data. By Melvin E. LaVerne and Aaron S. Boksenbom.
 1937. A Flight Investigation of the Effects of Compressibility on Applied Gust Loads. By E. T. Binkley and Jack Funk.
 1938. Mechanisms of Failure of High Nickel-Alloy Turbojet Combustion Liners. By John W. Weeton.
 1941. Attainable Circulation of Airfoils in Cascade. By Arthur W. Goldstein and Artur Mager.
 1943. Investigation of Bonding between Metals and Ceramics. 1—Nickel, Cobalt, Iron, or Chromium with Boron Carbide. By H. J. Hamjian and W. G. Lidman.
 1951. Method of Determining Conditions of Maximum Efficiency of an Independent Turbine-Propeller Combination. By Marcus F. Heidmann.
 1956. Equilibrium Operating Performance of Axial-Flow Turbojet Engines by Means of Idealized Analysis. By John C. Sanders and Edward C. Chapin.
 1980. Effect of Forebody Warp and Increase in Afterbody Length on the Hydrodynamic Qualities of a Flying-Boat Hull of High Length-Beam Ratio. By Walter J. Kapryan.

Large amounts of the material translated from the German are parts of two regular series of reports. Reference will be made to these series of German reports by abbreviations defined as follows:

ZWB—Zentrale für Wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalflutzeugmeisters (German Central Publication Office for Aeronautical Reports).

FB—Forschungsbericht (Research Report).

UM—Untersuchungen und Mitteilungen (Reports and Memoranda).

- No.
1161. Wind-Tunnel Tests on Various Types of Dive Brakes Mounted in Proximity of the Leading Edge of the Wing. By Bernardino Lattanzi and Erno Bellante From *Relazione Tecnica No. 10: Ministero dell' Aeronautica Direzione Superiore Studi ed Esperienze, 1 Divisione—Sezione Aerodinamica, Guidonia, December 1942*.
 1194. Force- and Pressure-Distribution Measurements on Eight Fuselages. By G. Lange. From ZWB, FB 1516, Oct. 24, 1941.
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 1199. Compression Shocks in Two-Dimensional Gas Flows. By A. Busemann. From *Vorträge aus dem Gebiete der Aerodynamik und verwandter Gebiete, Aachen, 1929*, pp. 162-169.
 1201. Rotation in Free Fall of Rectangular Wings of Elongated Shape. By Paul Dupleich. From *Publications Scientifiques et Techniques du Secretariat d'Etat a l'Aviation, No. 176, 1941*.
 1202. On Wind Tunnel Tests and Computations Concerning the Problem of Shrouded Propellers. By W. Krüger. From ZWB, FB 1949, Jan. 21, 1944.
 1203. The Compressible Flow Past Various Plane Profiles Near Sonic Velocity. B. Göthert and K. H. Kawalki. From ZWB, UM 1471, Jan. 6, 1945.
 1204. Some New Problems on Shells and Thin Structures. By V. S. Vlasov. From: *Izvestia Akademii Nauk, 1947, No. 1*, pp. 27-53.
 1205. Exact Calculation of Laminar Boundary Layer in Longitudinal Flow Over a Flat Plate with Homogeneous Suction. By Rudolf Iglisch. From *Mathematical Institute of the Technical Academy Braunschweig, Schriften der Deutschen Akademie der Luftfahrtforschung, Vol. 8B, No. 1, 1944*.
 1206. Systematic Investigations of the Effects of Plan Form and Gap Between the Fixed Surface and Control Surface on Simple Flapped Wings. By Göthert and Rüber. From ZWB, FB 532/4, Feb. 10, 1940.
 1207. The Theory of Plasticity in the Case of Simple Loading Accompanied by Strain-Hardening. By A. A. Il'yushin. From *Prikladnaya Matematika i Mekhanika, Vol. 11, No. 2, 1947*, pp. 293-296.
 1208. Calculation of Counterrotating Propellers. By F. Ginzler. From ZWB, FB 1752, Jan. 25, 1943.
 1209. Experimental Study of Flow Past Turbine Blades. By E. Eckert and K. v. Vietinghoff-Scheel. From *Vorabdrücke aus Jahrbuch 1942 der deutschen Luftfahrtforschung, 6. Lieferung*, pp. 2-10.

- No.
1210. Development of Spoiler Controls for Remote Control of Flying Missiles. By G. Ernst and M. Kramer. From ZWB, FB 1717, Jan. 6, 1943.
1211. The Characteristics Method Applied to Stationary Two-Dimensional and Rotationally Symmetrical Gas Flows. By F. Pfeiffer and W. Meyer-König. From ZWB, FB 1581, Mar. 20, 1942.
1212. On the Theory of the Laval Nozzle. By S. V. Falkovich. From Prikladnaya Matematika i Mekhanika. Vol. 10, No. 4, 1946, pp. 503-512.
1213. Gas Motion in a Local Supersonic Region and Conditions of Potential-Flow Breakdown. By A. A. Nikolskii and G. I. Taganov. From Prikladnaya Matematika i Mekhanika, Vol. 10, No. 4, 1946, pp. 481-502.
1214. Jet Diffusion in Proximity of a Wall. By D. Küchemann. From ZWB, UM 3057, Dec. 31, 1943.
1215. Flow Pattern in a Converging-Diverging Nozzle. By KL. Oswatitsch and W. Rothstein. From Jahrbuch 1942 der deutschen Luftfahrtforschung, pp. I 91-102.
1216. An Approximate Method for Calculation of the Laminar Boundary Layer with Suction for Bodies of Arbitrary Shape. By H. Schlichting. From Aerodynamisches Institut der Technischen Hochschule Braunschweig, Bericht 43/13, June 12, 1943.
1217. Lecture Series "Boundary Layer Theory". Part I—Laminar Flows. By H. Schlichting. (Given during Winter Semester 1941/2 at Luftfahrtforschungsanstalt Hermann Göring, Braunschweig) From ZWB, pp. 1-153.
1218. Lecture Series "Boundary Layer Theory". Part II—Turbulent Flows. By H. Schlichting. (Given during Winter Semester 1941/2 at Luftfahrtforschungsanstalt Hermann Göring, Braunschweig) From ZWB, pp. 154-279.
- No.
1219. The Influence of the Application of Power During Spin Recovery of Multiengine Airplanes. By P. Höhler. From ZWB, FB 1536, Feb. 12, 1942.
1224. Lamé's Wave Functions of the Ellipsoid of Revolution. By J. Meixner. From ZWB, FB 1952, June 1944.
1225. Test Report on Three- and Six-Component Measurements on a Series of Tapered Wings of Small Aspect Ratio. (Partial Report: Trapezoidal Wing) By Lange/Wacke. From ZWB, UM 1023/1, Sept. 15, 1943.
1229. Heat Transmission in the Boundary Layer. By L. B. Kalikhman. From Prikladnaya Matematika i Mekhanika, Vol. 10, 1946, pp. 449-474.
1230. Effect of the Acceleration of Elongated Bodies of Revolution Upon the Resistance in a Compressible Flow. By F. I. Frankl. From Prikladnaya Matematika i Mekhanika, Vol. 10, No. 4, 1946, pp. 521-524.
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1234. Computation of Thin-Walled Prismatic Shells. By V. Z. Vlasov. From Prikladnaya Matematika i Mekhanika, Vol. 8, No. 5, 1944.
1238. Two-Dimensional Wing Theory in the Supersonic Range. By H. Hönl. From ZWB, FB 1903, Jan. 6, 1944.
1240. Airfoil Measurements in the DVL High-Speed Wind Tunnel (2.7-Meter Diameter) By B. Göthert. From Lilienthal-Gesellschaft für Luftfahrtforschung, Report 156, pp. 5-16.
1249. Susceptibility to Welding Cracking, Welding Sensitivity, Susceptibility to Welding Seam Cracking, and Test Methods for these Failures. By K. L. Zeyen. From ZWB, Luftfahrtforschung, Vol. 20, No. 8/9, Oct. 10, 1943, pp. 231-241.

Part II—COMMITTEE ORGANIZATION AND MEMBERSHIP

The act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics (U. S. Code, Supplement II, title 50, sec. 151), as amended by act approved March 25, 1948 (Public Law 549, 80th Cong.), provides that the Committee shall consist of 17 members appointed by the President, and shall include "two representatives of the Department of the Air Force; two representatives of the Department of the Navy, from the office in charge of naval aeronautics; two representatives of the Civil Aeronautics Authority; one representative of the Smithsonian Institution; one representative of the United States Weather Bureau; one representative of the National Bureau of Standards; the Chairman of the Research and Development Board of the National Military Establishment; and not more than seven other members selected from persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter seven members serve for terms of five years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

The retirement of Maj. Gen. Edward M. Powers from the Air Force resulted in the termination of his membership on the Committee, and under date of March 22, 1949, the President appointed Maj. Gen. Donald L. Putt (then Brigadier General), Director of Research and Development in the Air Force, to succeed General Powers as a member of the Committee.

Effective December 1, 1948, the President reappointed Mr. William Littlewood and Dr. Theodore P. Wright, members from private life, for 5-year terms.

Because of his resignation as Assistant Secretary of Commerce for Aeronautics, Hon. John R. Allison has submitted his resignation as a member of the NACA representing the Civil Aeronautics Authority, and his successor on the Committee has not yet been appointed.

In accordance with the regulations governing the organization of the Committee as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee.

On October 20, 1949, Dr. Jerome C. Hunsaker was reelected Chairman of the NACA and of the Executive Committee, and Dr. Alexander Wetmore and Dr. Francis W. Reichelderfer were reelected Vice Chairman of the NACA and Vice Chairman of the Executive Committee, respectively.

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 Mr. Albert A. Vollmecke, Civil Aeronautics Administration.
 Dr. Hugh L. Dryden (ex officio).
 Dr. Henry J. E. Reid, NACA Langley Aeronautical Laboratory.
 Mr. Carlton Bioletti, NACA Ames Aeronautical Laboratory.
 Mr. Don O. Benson, Northwest Airlines, Inc.
 Prof. Raymond L. Bisplinghoff, Massachusetts Institute of Technology.
 Dr. Emerson W. Conlon, University of Michigan.
 Dr. C. C. Furnas, Cornell Aeronautical Laboratory.
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 Mr. Albert Erickson, NACA Ames Aeronautical Laboratory.
 Mr. Samuel S. Manson, NACA Lewis Flight Propulsion Laboratory.
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Part III—FINANCIAL REPORT

Appropriations for the fiscal year 1949.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1949 in the Independent Offices Appropriation Act, 1949, approved April 20, 1948, and the Second Deficiency Appropriation Act, 1949, approved June 23, 1949.

Salaries and expenses.....	\$38,557,000
Printing and binding.....	95,000
Construction and equipment of laboratory facilities:	
Langley Aeronautical Laboratory.....	4,188,650
Ames Aeronautical Laboratory.....	370,300
Lewis Flight Propulsion Laboratory.....	5,441,050
Total appropriations.....	48,652,000

The amount appropriated for construction and equipment of laboratory facilities includes \$2,143,000 for liquidation of the obligations incurred under the contract authority provided in the appropriation act for the fiscal year 1948. The remainder, \$7,857,000, is available for obligation during the fiscal years 1949 and 1950. Additional contract authority was provided for construction and equipment of laboratory facilities in the amount of \$18,200,000 in the 1949 act, for obligation during fiscal years 1949 and 1950.

Obligations incurred against the fiscal year 1949 appropriations are listed below. The figures shown for salaries and expenses include the costs of personal services, travel, transportation, communication, utility services, contractual services, supplies, and equipment.

Salaries and expenses:	
NACA Headquarters.....	\$763,159
Langley Aeronautical Laboratory.....	16,258,616
Ames Aeronautical Laboratory.....	6,133,977
Lewis Flight Propulsion Laboratory.....	14,303,563
Research Contracts—educational institutions....	603,172
Transfer to National Bureau of Standards.....	175,000
Printing and binding, all activities.....	94,895
Construction and equipment of laboratory facilities:	
Langley Aeronautical Laboratory.....	2,397,638
Ames Aeronautical Laboratory.....	359,864
Lewis Flight Propulsion Laboratory.....	3,583,830
Total obligations.....	44,673,778

Unobligated balances:

Salaries and expenses.....	319,503
Printing and binding.....	105
Construction and equipment.....	3,658,609

Total appropriations.....	48,652,000
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The following obligations were also incurred against the fiscal year 1949 additional contract authority provided for construction and equipment of laboratory facilities:

Langley Aeronautical Laboratory.....	\$3,550,872
Ames Aeronautical Laboratory.....	395,622
Lewis Flight Propulsion Laboratory.....	3,833,478

Total obligations, fiscal year 1949.....	7,785,972
Total available for obligation, fiscal year 1950.....	10,414,028

Total authorization.....	18,200,000
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Appropriations for the fiscal year 1950.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1950 in the Independent Offices Appropriation Act, 1950, approved August 24, 1949:

Salaries and expenses.....	\$43,000,000
Construction and equipment of laboratory facilities:	
Langley Aeronautical Laboratory.....	4,700,200
Pilotless Aircraft Research Station.....	771,000
Ames Aeronautical Laboratory.....	960,000
Lewis Flight Propulsion Laboratory.....	3,562,800

Total appropriations.....	53,000,000
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The \$10,000,000 appropriated for construction and equipment of laboratory facilities includes \$7,277,200 for liquidation of obligations incurred pursuant to the contract authorization contained in the appropriation act for the fiscal year 1949. The remainder, \$2,722,800 is available for obligation during fiscal years 1950 and 1951 in accordance with the appropriation act for fiscal year 1950. Additional contract authority for construction and equipment of laboratory facilities in the amount of \$10,000,000 was also provided in the 1950 act, for obligation during the fiscal years 1950 and 1951.